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AN AUTECOLOGICAL STUDY OF BLACKBRUSH  
(COLEOGYNE RAMOSISSIMA TORR.)  
IN SOUTHWESTERN UTAH

JAMES E. BOWNS

1973



AN AUTECOLOGICAL STUDY OF BLACKBRUSH (COLEOGYNE RAMOSISSIMA TORR.)

IN SOUTHWESTERN UTAH

by

James E. Bowns

A dissertation submitted in partial fulfillment  
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Range Science  
(Ecology)

Approved:

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Major Professor

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Committee Member

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Committee Member

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Committee Member

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Committee Member

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Dean of Graduate Studies

UTAH STATE UNIVERSITY  
Logan, Utah  
1973

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*James E. Bowns*

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## ABSTRACT

An Autecological Study of Blackbrush  
(Coleogyne ramosissima Torr.) in Southwestern Utah

by

James E. Bowns, Doctor of Philosophy

Utah State University, 1973

Major Professor: Dr. Neil E. West

Department: Range Science

The purpose of this study was to provide basic ecological information on an important but little studied major vegetation type through autecological investigations of the dominant species. Data include climate and soils where this species occurs, root distribution, phenology and growth, seed germination requirements and seedling survival. Percent ground cover provided by blackbrush and other dominant plants as well as the composition of herbaceous understory vegetation was presented. Leaf and stem anatomy of blackbrush revealed features typical of desert shrub species with stem splitting appearing to be a characteristic of this species.

Blackbrush is characterized as a poor forage species of low palatability. Nutrient content analysis provided data on ether extract, carotene, phosphorus, acid detergent fiber, crude protein, and lignin. Nutrient deficiencies occur during the winter when blackbrush ranges are grazed by domestic livestock.

Brush beating or some similar method which will remove the old woody material from the plants was proposed as a method of increasing the forage quality without changing the entire community as is done with burning.

( 115 pages)

## INTRODUCTION

Blackbrush (Coleogyne ramosissima Torr.) dominates probably the least studied major vegetation type in the conterminous United States. K  chler (1964) indicates that more than one million hectares of this type exist in Utah. Blackbrush is also important in northern Arizona, southern Nevada, southeastern California, and southwestern Colorado.

A search of the literature soon makes it apparent that little published information is available on blackbrush or the area it dominates. This author's residence in southwestern Utah resulted in an awareness of the vast acreages of blackbrush in that region and the lack of scientific studies available for guiding management decisions.

The objectives of this study were to provide basic ecological data on this species which would serve as a basis for management or which would lead to more basic or applied research.

## REVIEW OF LITERATURE

Blackbrush is a member of the Rosaceae family and the sole species in the genus Coleogyne. The dark gray bark turns black when wet, hence the name "blackbrush" (Benson and Darrow, 1944). It is a densely branched shrub up to two meters tall with ash-gray branches, these being opposite, tangled and spinescent at the apex. The opposite leaves are 5-15 mm long and about 1-1.5 mm wide, clavate or linear, strigose with the hairs attached at the middle. Flowers are solitary and terminal on the young branchlets. Petals are usually lacking, but Kearney and Peebles (1960) refer to a specimen collected in Mohave County, Arizona that had two pale-yellow obovate petals opposite to and considerably longer than the outer sepals. Sepals are four-merous 5-8 mm long, yellowish, greenish or purplish. Stamens are numerous, and inserted at the base of a sheathing disc that encloses the ovary. The fruit is an achene about 3 mm long, glabrous, with a bent, twisted, exserted style, this very densely villous at the base (Harrington, 1954; Kearney and Peebles, 1960).

Kearney and Peebles (1960) report blackbrush in Arizona from Apache County to Mohave and Yavapai counties between 915 and 1980 meters elevation in well-drained, usually gravelly soils on open plains and mesas, sometimes in pure stands to the exclusion of other shrubs. The plants are browsed by sheep and goats and to a lesser extent by cattle, and withstand heavy browsing successfully. Blackbrush distribution, according to Benson and Darrow (1944), is on slopes and mesas in the upper creosote-bush desert and the lower sagebrush desert at 920 to 1540 meters elevation. It occurs in California in the Mojave Desert and on the western border of the Salton Sea Basin of the Colorado Desert; southern Nevada; Utah; south-

western Colorado; northern Arizona along the Colorado and Little Colorado river drainages and southward in the Mojave Desert in Mohave and Yavapai counties. Benson and Darrow (1944) further note that blackbrush occurs abundantly in southern Utah and northern Arizona and forms pure stands in large areas in the transition region between the creosote-bush and sagebrush deserts.

Beatley, (1969) reported that Coleogyne communities at the Nevada Test Site are most commonly either: (1) those in which Coleogyne occurs in nearly pure stands or (2) Coleogyne within which are scattered clumps of Grayia spinosa and Lycium andersonii, or these species and Larrea tridentata. Coleogyne is nearly always associated with stoney soils, and occurs mostly at elevations of 1220 to 1520 meters. In the lower elevational communities, Yucca brevifolia may be a prominent associate, and at higher elevations, Yucca baccata shows dominance. She reported Coleogyne as essentially absent in areas where soils are primarily sands, derived from the volcanic rocks of the region. The communities of which Coleogyne is a dominant are interpreted as belonging strictly neither to the Mojave Desert nor the Great Basin Desert, but occupying a position of intermediacy between the Larrea and Artemisia-Atriplex types which characterize the two desert regions. Randall (1972) also places blackbrush at middle elevations between creosote bush and big sagebrush in southern California.

Tidestrom (1925) characterized blackbrush as a secondary vegetation belt that overlaps and forms what he termed an imbricating belt. This blackbrush belt overlaps the boundary between the Larrea and Artemisia belts which rarely meet on the same level. He reports the gap between these belts as being 100 or more meters in altitude. Merriam (1893)



includes blackbrush in the Grayia belt which occupies the strip between the upper limit of Larrea and the lower border of the true sagebrush which indicates the beginning of the Upper Sonoran Zone. He states that the vertical limits of the zones are fixed by the temperature during the period of growth and reproduction. Based on physiognomy, community structure and floristic composition, Shreve (1942) lists blackbrush as part of the Great Basin Desert. He states that it is found only on rather coarse soils very low in salt content. Wallace and Romney (1972) reported rooted cuttings of blackbrush to be moderately tolerant of salinity but did not see evidence to support this in the field. On the contrary, they found blackbrush only on nonsaline soils, usually of calcareous nature. The sensitivity of seeds to salinity was thought to be a possible limiting factor governing the distribution of this species.

Wallace, Romney and Ashcroft (1970) provide further evidence that blackbrush occupies an intermediate position between the hot and cold deserts. They found that blackbrush grew best at intermediate temperatures (21 C) and growth decreased at both the low (16 C) and high (28 C) temperatures. They also reported that blackbrush seeds required special treatment for germination. Germination was achieved by placing seeds in moist vermiculite at 4 C for two weeks.

Bradley (1964) subdivided the desert scrub vegetation of the Desert Game Range in southern Nevada into (1) creosote bush, (2) blackbrush, (3) saltbush, and (4) desert riparian communities. He placed these communities under the Lower Sonoran category of Merriam's life zones. Bradley (1964) also reported that the present day composition and distribution of the plant communities of southern Nevada has developed since the last pluvial period (approximately 20,000 years ago) and probably during the

last 10,000 years. Blackbrush covers approximately 355,000 hectares on the Desert Game Range.

Shantz in Tidestrom (1925) called this vegetation type a Joshua tree association. He reported that blackbrush is best developed on the upper bajadas at elevations of 1300 to 1800 meters, but does occur occasionally down to about 1200 meters on the north-facing slopes. On arid south-facing slopes and small isolated mountains, it is found up to and occasionally above 2000 meters. In general, the soils of the upper bajada are more permeable, better drained and have lower salt concentrations than at lower elevations. Bradley (1964) described this situation in southern Nevada as having a well-developed gray desert soil.

The climate of the blackbrush community is cooler and wetter than that of the creosote bush community. Snow commonly falls during the winter, but does not remain on the ground for long periods (Bradley and Deacon, 1967). These authors characterize the blackbrush community as dominated by a closely-spaced matrix of low, dark-gray blackbrush interspersed with other desert shrubs. Cacti are not as abundant, but grasses are more abundant than in the creosote bush community.

Bradley (1965) found that in the blackbrush community the perennial grasses were most abundant on south-facing slopes where shrub cover was sparse as contrasted with north-facing slopes where shrub cover was highest. His general impression was that perennial bunch grasses are more prominent on arid rocky slopes where shrub cover is reduced. A personal visit to this area substantiated this observation and revealed that Stipa speciosa Trin. & Rupr. and Bouteloua eriopoda Torr. were the dominant perennial grasses and Bromus rubens L. and B. tectorum L. the dominant annual grasses.

Humphrey (1953) reported blackbrush in Mohave County, Arizona as occurring in essentially pure stands or as a dense understory beneath Joshua trees. Where it borders on other types, it may be intermixed with other shrubs or grasses. Blackbrush is also locally abundant in the northern parts of Coconino, Navajo, and Apache counties where it tends to form dense stands that permit the growth of little other vegetation (Humphrey, 1955).

Humphrey (1953) is of the opinion that ranges where there are presently dense stands of blackbrush never produced much more forage than they do today. He considered such areas as largely wasteland and until effective control methods are developed, attempted improvement would be largely wasted effort. Plummer, Christensen and Monsen (1968) in Utah, however, speculate that valuable associated species have largely been lost from the blackbrush type as a result of overgrazing. They also feel that there is a good opportunity to increase the forage and soil protection abilities in this type by reducing the competitive blackbrush and seeding palatable herbs and shrubs. According to Plummer, Christensen and Monsen (1968) the annual precipitation on blackbrush sites varies from 150 to 400 mm.

It has been reported that blackbrush range does not lend itself well to range condition classification. Even those stands that have not been modified by grazing may contain little except blackbrush. Because of the low palatability, the composition or productivity of these stands change little under grazing pressure (Humphrey, 1955). Humphrey hypothesized that the extremely abrupt boundaries of blackbrush apparently indicate either a specific soil or soil-moisture requirement.

Blackbrush is generally thought to be a rather poor forage species.

Humphrey (1953, 1955) indicates that it is probably poor forage during the spring, summer, and fall for cattle, horses, and sheep, but goats make fair use of it during these seasons. During the winter when other feed is scarce, it sometimes rates fair for cattle and sheep. At best, however, he considers the plant as a poor forage species and this type as usually largely wasteland from the stockman's point of view. Sampson and Jespersen (1963) rate the browse value of blackbrush as good to poor for goats and deer; fair to poor for sheep; poor for cattle and useless for horses. Jenson, Buzan, and Dimock (1960) set the stocking rate of unburned blackbrush range in southern Nevada from 12 to 24 hectares per animal unit month.

The principal forage value of blackbrush appears to be as a browse species for desert bighorn sheep. It has been found to be a major species in the diet of these animals (Bradley, 1965; Bradley, 1968; Wells and Wells, 1950; Wilson, 1967). Grass was reported to be the most important forage for bighorns, either cured or green. Shrubs were most important in late summer, fall and early winter (Bradley, 1968).

Local stockmen who operate in southwestern Utah indicated to this author that blackbrush is a fair forage plant for their cattle when it is actively growing in the spring, but they feel that the annuals, especially filaree (Erodium cicutarium L.) are the better forage species. Sheepmen also consider blackbrush to be good sheep forage during the spring growing season, but the plants have a tendency to pull out the wool.

An important management decision which arises with regard to blackbrush is whether or not to burn the stands. The Las Vegas District of the Bureau of Land Management evaluated a series of blackbrush burns that varied in age from 12 to 21 years to determine future policy relating to blackbrush



burning and management of this range type on both burned and unburned areas (Jenson, Buzan, and Dimock, 1960). There were differences of opinion and recommendations by the evaluation committee; however, the following unanimous opinions were expressed: (1) burning effectively destroyed the blackbrush cover and this species had failed to reestablish itself; (2) plant succession varied widely on the different sites, with different plant species dominating on different burns; (3) increased density of annual species was very significant the first two or three years following the burn. There was a wide variation in production of annuals depending on winter and spring weather conditions; (4) replacement shrubs on the burns were largely undesirable forage species; (5) perennial grasses made no appreciable recovery following burning. They felt grazing use following most burns probably influenced perennial grass production and (6) it appeared that if desirable perennials were not established within the first few years following the burn, that there was little possibility that they would become established under present management practices. The majority of the committee expressed the opinion that an accumulation of litter resulting from the heavy growth of annuals was evident on most burns and was contributing substantially to soil stability. They also speculated that the increased forage production by annuals represented a very substantial benefit to the range economy; they indicated stocking rate increases from at least 8 to 10 times. The dissenting member, however, felt that the protective cover of the annuals was nowhere equal to the shrub cover provided by the unburned blackbrush.

Work in southern Nevada revealed poorer watershed conditions and more soil movement on areas where blackbrush had been burned than areas of existing blackbrush. Blackbrush had not reappeared on a burned site in a period

of 20 years. The total density of the plant cover had approximately doubled in that period, but this was attributed to expansion of crown cover of existing plants rather than new individual plants (Letter, accompanied by field data, dated 21, September 1972 from James R. Brunner, Bureau of Land Management, Las Vegas, Nevada.).

West (1969) indicates that in southeastern Utah blackbrush fits into two situations: (1) it has invaded desert grassland after grazing abuse. Its presence on deep, loessal soils probably represents this situation; and (2) it is reasonable to expect this shrub as a climatic climax dominant on drier (130 to 150 mm annual precipitation) sites with residual soil over sandstone, as relict areas in and near Canyonlands National Park attest.

Wells (1967) refers to blackbrush in Gold Valley, California as the invading species and therefore presumably well adapted. Beneath the shrubs he found less drastic changes in air temperature and surface soil temperatures between day and night. Evaporation beneath the shrubs was also less. The blackbrush shrubs also improved the productivity of annuals by (1) better soil moisture conditions early in the season, and (2) more favorable nutrient status with respect to nitrogen (and presumably phosphorus) under the shrubs. He felt that succession to shrubs in these areas may be regarded as an important natural means of replenishing the soil with organic matter.

## STUDY AREA

This study was conducted in the extreme southwestern corner of Utah near the upper reaches of the Beaver Dam Wash and the town of Gunlock, located at  $37.5^{\circ}$  north latitude and  $114^{\circ}$  west longitude. Two study sites were located near the old settlement of Motoqua and one near Gunlock (Figure 1). This study area is in the region designated by Noel Holmgren in Cronquist et al. (1972) as the Dixie Corridor. Blackbrush occupies many hectares in Washington County, Utah and is used as livestock range for large numbers of both cattle and sheep. This type is found in essentially pure stands or in association with Joshua tree (Yucca brevifolia Engelm.) on the lower sites and with Utah juniper (Juniperus osteosperma (Torr.) Little) on the upper sites. One study site, an essentially pure stand of blackbrush and referred to in this presentation as the blackbrush site, is at an elevation of 1280 m (Figure 2); the site with an overstory of Utah juniper is also at 1280 m and is referred to as the juniper-blackbrush site (Figure 3); the lower site at an elevation of 1190 m has a Joshua tree overstory and is referred to as the Joshua tree-blackbrush site (Figure 4). A 0.4 hectare study plot was fenced at each site and used as the experimental area.

The blackbrush type is practically all under government ownership. In this region it is managed by the U.S. Bureau of Land Management (B.L.M.). The Shivwits Indian Reservation also contains considerable acreage of blackbrush and is grazed by cattle. The B.L.M. is interested in converting portions of the blackbrush type to grasses or other more desirable forage plants. Large acreages near the study sites have been converted with seemingly good results. The areas selected for conversion have been areas of blackbrush with a juniper overstory at the higher elevations or near the mountains.

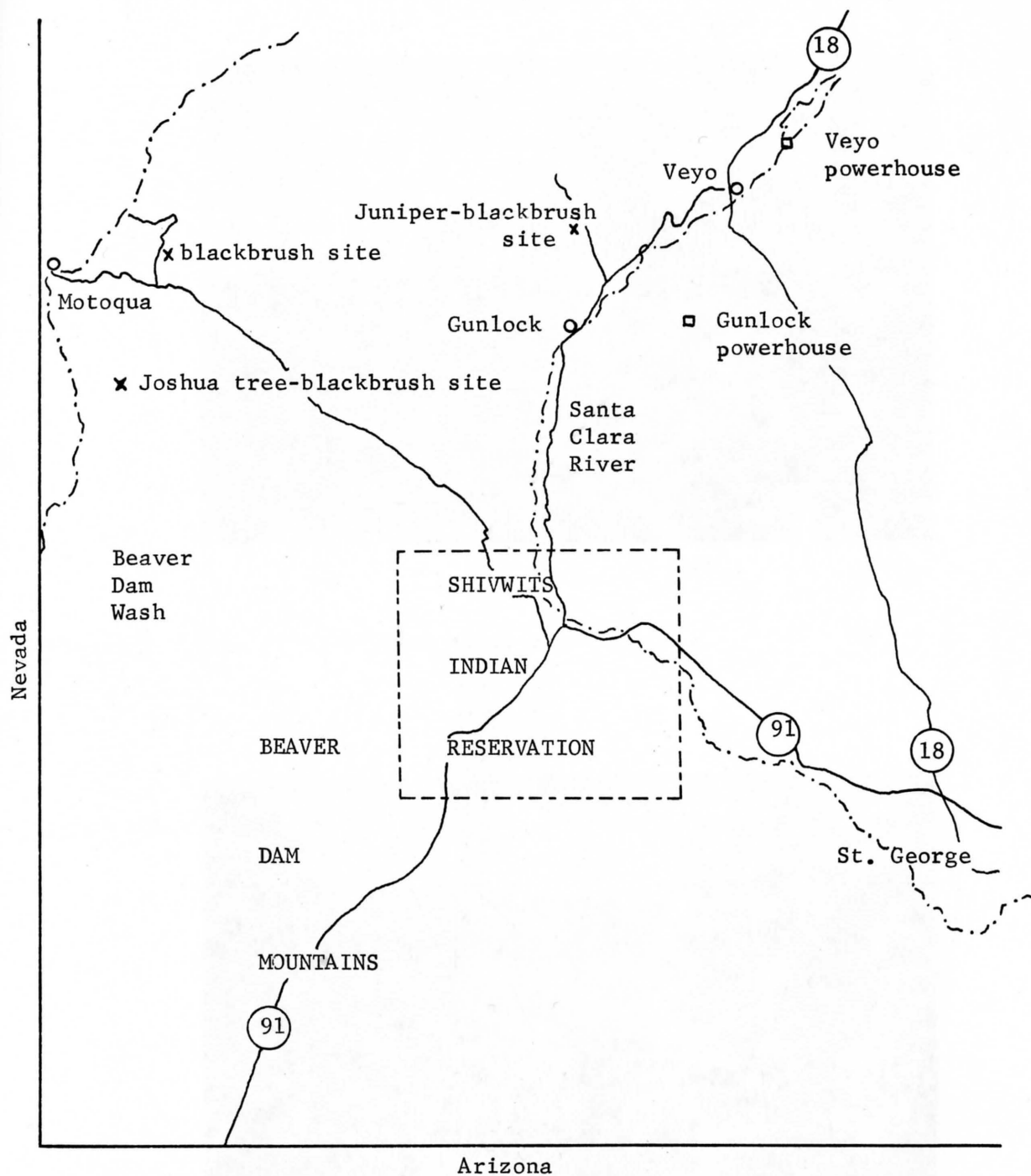


Figure 1 Map of southwestern Utah showing location of blackbrush study sites. Numbers enclosed in circles denote highways and broken lines denote streams.

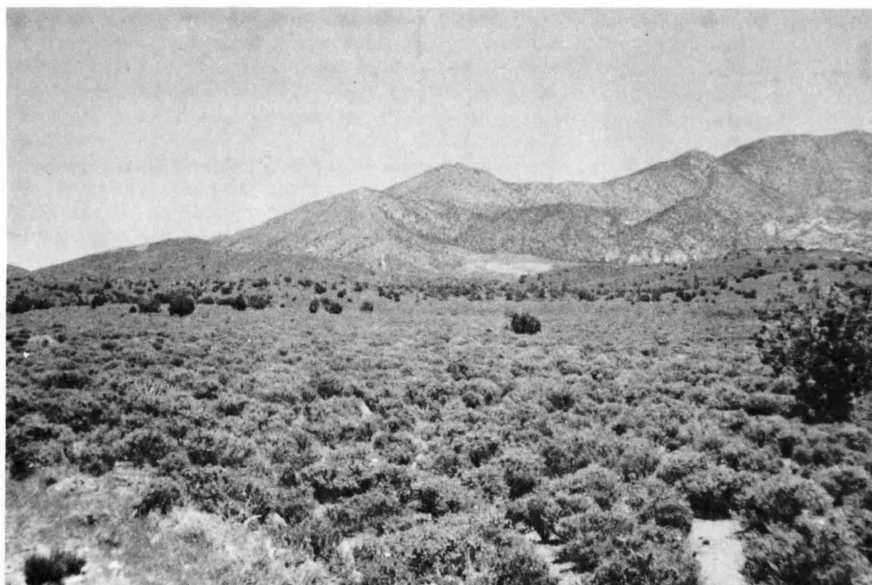


Figure 2 View of blackbrush study site.



Figure 3 View of juniper-blackbrush study site.

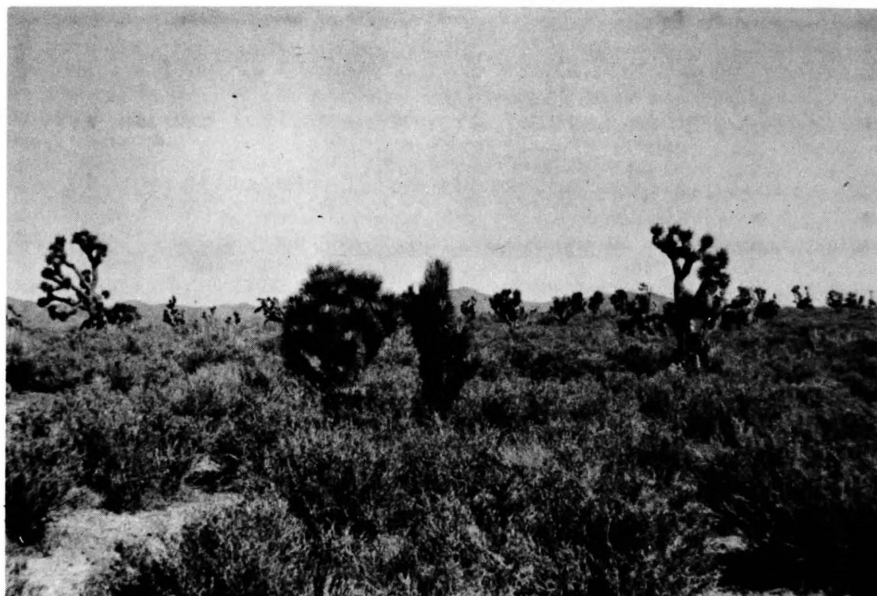


Figure 4 View of Joshua tree-blackbrush study site.

## METHODS AND PROCEDURES

Air Temperatures

Air temperatures and relative humidities were recorded during the growing seasons and the summer months through mid-September. These data were collected with Bendix Model 594 hygrothermographs located at the Joshua tree-blackbrush and juniper-blackbrush study sites. These instruments plus a maximum-minimum thermometer were housed in white, wooden instrument shelters. These instruments were located at the height of the shrub canopies, or approximately 35 cm above the soil surface. Chart readings were corrected by means of the maximum-minimum thermometers for temperatures and a sling psychrometer for relative humidities. Calibration curves were constructed from sling psychrometer readings and corrected readings taken from these charts. Temperature readings were of sufficient accuracy as not to require calibration charts.

Precipitation

Precipitation data were obtained at the study plots from April 1969 through March 1972. These data were obtained from 200 mm totalizing rain gauges and weighed with a standard weather bureau scale. Data from the study plots were supplemented with B.L.M. precipitation measurements taken near the blackbrush and juniper-blackbrush plots.

Soils

Soil profile descriptions were made at each site. Descriptions were provided by Mr. Vear Mortensen, Soil Scientist, Soil Conservation Service U.S.D.A. Complete profile descriptions are presented in the appendix. Chemical and physical analyses are also provided.

Soil moisture data were obtained by the use of a SOILTEST MC-300 A Moisture Meter and MC-310A Soil Moisture Cells. These cells are also referred



to as fiber glass or Coleman units.

Moisture cells were installed in the soil around one selected, representative plant at each study site. These plants were selected so as to have an open area completely around the plant. Moisture cells were placed in the soil at 5 cm and 20 cm depths which coincide respectively with the upper rootless zone and the zone of maximum root biomass. Cells were located at the north, east, south and west sides of the plant beneath the canopy and in the open areas one-half meter beyond the outer edge of the canopy. A total of 16 cells were placed around each plant.

Probes were inserted into undisturbed soil in such a manner that good contact was made with the soil and so that the probe would not inhibit the vertical movement of soil water. The electrical leads were covered by approximately 5 cm of soil and brought to a point where the probes could be read conveniently and so that no soil compaction took place around the probes. Rodents caused problems with the probes because of their tendency to dig in any area that shows soil disturbance. This was a problem until the soil surface revealed no signs of disturbance. Readings were taken at weekly intervals during the spring and summer growing season and monthly thereafter. Soil temperature readings were taken concurrently with soil moisture. These readings were usually taken between 10:00 a.m. and 3:00 p.m. although some readings were taken later in the afternoon.

Calibration curves were constructed through the use of drying curves and soil moisture was expressed as per cent water content based on the oven dry weight of the soil. Only the drying cycle was used and hence hysteresis was neglected. The drying curve was constructed by placing approximately 1500 grams of soil in a liter cardboard container. Approximately 20 seeds of barley or oats were planted at 1 cm, then the surface was covered with a



thin layer of molten plumber's toilet bowl wax. Readings were then taken from the moisture cells and weight changes of the containers recorded. Samples of surface soil beneath the canopy, surface soil in the open area and a sample at 20 cm were used to calibrate the soils from each plot. Calibration curves were obtained from these data.

#### Root Distribution

Root distribution was determined by two methods. The ice pick method (Weaver, 1926) was first employed to establish the overall root distribution in the soil. A pit was dug adjacent to a clump of blackbrush then the soil was removed from the face of the pit leaving the roots exposed. This method did provide data on the distribution of the larger roots but was not satisfactory for the finer roots nor did it provide any quantitative measure of the roots in relation to distance from the plant or with increasing depth. Once the general root distribution was determined it was necessary to get a quantitative measure of the roots by the removal of soil blocks and washing the roots from these soil blocks.

Because of the excessive amount of time and labor involved in the process, it was deemed necessary to excavate roots from only the Joshua tree-blackbrush and the blackbrush study sites. Plants were selected that allowed for an open area in two directions. A long pit was excavated adjacent to the plant to be removed. Soil samples 20 cm long, 15 cm wide and 10 cm deep were then removed and placed in individual paper sacks. Six such samples were taken laterally on each side of the plant and samples taken as deep as 40 cm. These samples were washed through a 2 mm screen box to remove the soil. Because of the large amount of coarse fragments and gravel in these soils, it was necessary to wash each sample again in a large bowl and float the roots away from the rock fragments. Any roots remaining with the rock were picked up with small forceps. Apparently this was an effective

method for determinations of root contents. Each sample of roots was then air-dried and weighed to the nearest 0.1 gram.

### Phenology and Growth

Four randomly selected 33 m lines were located in each of the study sites for the determination of phenology and growth patterns. Each line included five plants selected at random 3 m intervals along the line, the selected plant being the one nearest the designated 3 m point. Each plant was permanently marked with a painted stake.

Individual branches were marked with red, plastic bag sealers and a small spot of india ink. It appeared that the ink had no effect on the stimulation or retardation of growth or flower development. Blackbrush lacks bud scales; hence current year's growth cannot be determined from terminal bud scale scars. Growth measurements were made at approximately weekly intervals with a millimeter scale. Phenological development was determined at the time the growth measurements were made.

During the first year of the study two branches were tagged on each plant, these were a terminal branch and a lateral branch. It soon became apparent that some of the terminal branches grew longer and more rapidly than others. These were branches arising from nearer the base of the plants rather than at the edge of the canopy. In subsequent years terminal, lateral and these basal branches were tagged and growth of these determined.

### Seed Germination

Blackbrush seeds were collected in June and July of 1969 for determination of viability and requirements for germination. Seeds were stored in paper sacks at room temperature until April 1970, when germination trials were carried out in a growth chamber for 40 days.

Seeds from each location were divided into two samples which were

stratified at 4 C on moist filter paper for 23 days. Personal communication with A. Wallace pointed out the stratification requirement. One sample was kept in the dark by means of aluminum foil while the other sample received intermittent flashes of light. A control group was comprised of seeds taken from the storage sacks at the time the samples were placed in the growth chamber. Each treatment was then divided into four replications of 25 seeds each.

Twenty-five seeds were then placed in a wheel spoke pattern on 1.5 per cent agar-agar suspension in a petri dish. A core was removed from the center of the agar which served as a storage reservoir and prevented water from accumulating on the surface of the agar as recommended by Workman (1967). A 12-hour photoperiod was used with a 14 C daytime temperature and a 4 C nighttime temperature. Temperatures for this experiment were determined by recording the 5 cm soil temperatures during early morning and afternoon at the time seed germination was noted in the field. Light intensity during the experiment was 1720 lumens. A green safe light with an emission spectrum between 0.50 to 0.55 microns was used to determine germination at daily intervals. Design for this experiment was a 3x3x2 factorial.

#### Seedling Survival

Eight plots measuring 10 meters x 0.5 meters, located at each study site and permanently marked, were used to determine seedling establishment and survival. These plots were checked at 3 month intervals in March, June, September and December. These periods coincided, respectively, with the time of seed germination, the end of the growing season, the end of the most extreme summer temperatures, and the end of the cooler, more-moist autumn. Each plot was carefully checked for seedlings and, with the

exception of the March period, each seedling was individually marked with a small aluminum tag attached at the soil surface a short distance from the seedling. The abundance of seedlings during the March reading made it impractical to tag each individual seedling. Each seedling was measured and its condition recorded at each period. Measurements did not prove to be satisfactory because the soil surface was often eroded between readings and what may have appeared to be growth was actually only the removal of soil from around the seedlings. In June, soil moisture was depleted and the seedlings appeared to become dormant much like the mature plants. At this point it was extremely difficult to determine whether a seedling was alive or dead.

#### Understory Herbaceous Plants

Four randomly selected lines were established at each study site for the measurement of herbaceous species. These lines were 25 meters long and permanently located by stakes at each end. A steel tape was precisely located above the stakes and 0.1 square meter plots were read at one meter intervals along these lines. A total of 100 plots were read at each study site during the early part of May when the herbaceous vegetation was at its peak growth stage.

The number of individuals of each species, the average height of the plants and the overstory provided by the blackbrush plants were recorded in each plot. Density, frequency and average height were determined for each study site each year.

#### Blackbrush Cover

Blackbrush cover was determined by means of 70 mm low altitude color aerial photography. Photographs taken of the Joshua tree-blackbrush and blackbrush sites resulted in a scale of 1:160, and a 1:240 scale for the

juniper-blackbrush site. Markers of 0.1 square meter dimensions were scattered throughout the plots and used to determine the scale. A 9 square meter plot was drawn on a plastic overlay and used as the sample plot. Fifty randomly selected plots were used to determine the per cent cover. This resulted in a 50 per cent sample of the Joshua tree-blackbrush and blackbrush sites and a 45 per cent sample of the juniper-blackbrush site. A dot grid was used in conjunction with the sample plot overlay. Care was taken to minimize errors caused by shadows.

#### Nutrient Content

Thirty randomly selected plants were located along the same lines established for phenology and growth and used for the determination of nutrient content. A composite sample was taken from each plot and separated into leaves and stems. Stems were selected, as near as possible, to include only current year's growth. In all cases the samples were taken from the younger stems which were thought to be utilized by grazing animals. Samples collected in May, August, November and February 1969, were analyzed for ether extract, carotene, phosphorus, acid detergent fiber, crude protein, and lignin. These collection dates represent the spring growing season, summer, autumn and winter periods, respectively. All chemical analysis was conducted by the Wade Analytical Laboratory, Idaho Falls, Idaho.

#### Simulated Brush Beating

Plants located adjacent to those selected for nutrient content were cut off near the soil surface to simulate brush beating. These plants were treated in the late summer of 1970, and a qualitative evaluation was made after the 1971 growing season.

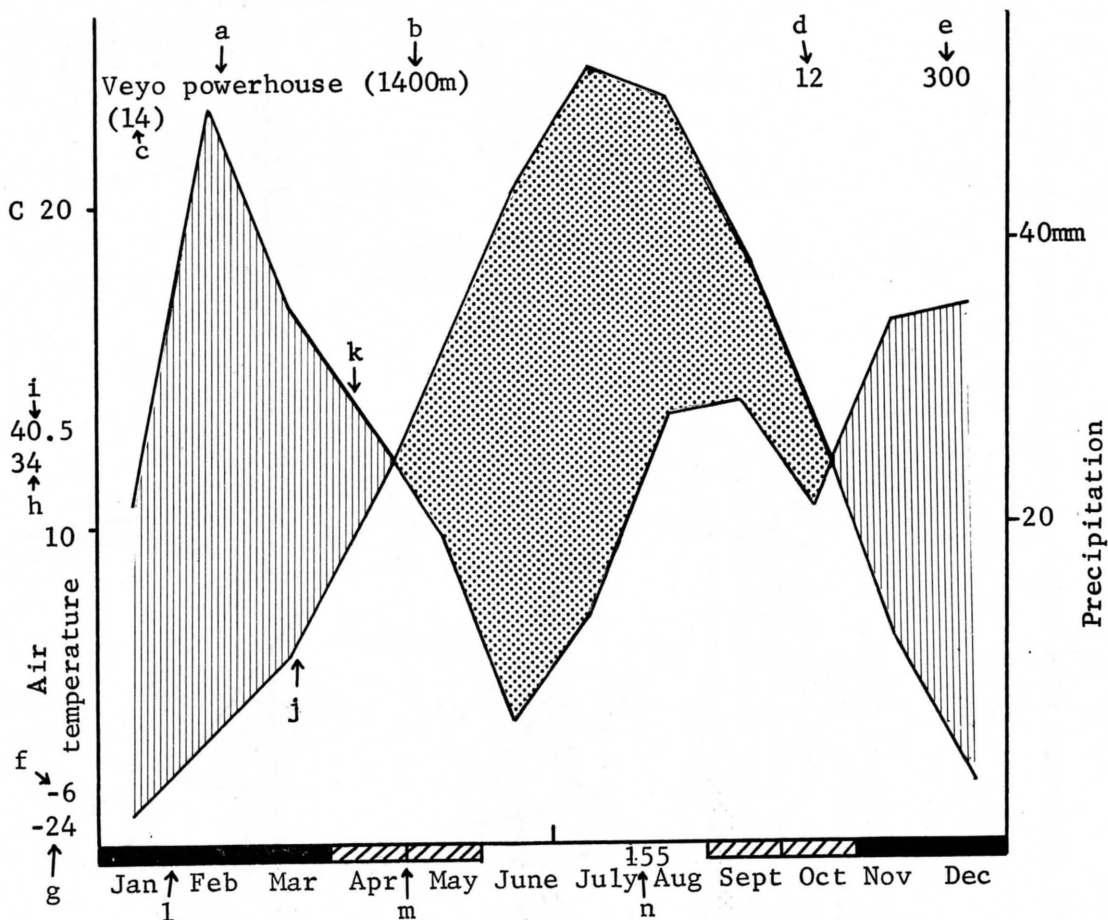
## RESULTS

### Climatic Diagram

A close correlation exists between vegetation and climate. It is very difficult, however to get an exact idea of climate. Walter (1963) defines climate "as the weather, changing in a certain manner during the course of a year, taken as an average of many years, as a single year may be abnormal." He goes on to define weather as "the effect of all weather or climatic elements as temperature, rainfall, humidity, radiation, etc., combined at a certain moment. Therefore, to get the actual climate, it is necessary to summarize the effects of all these climatic elements in order to get the weather for the entire year." Walter also feels that it is not possible to express climate by a figure or by formulae, even the most complicated ones, because it is necessary to know the seasonal rhythm of the most important factors. He therefore proposes the use of a diagram which he refers to as a climatic diagram. The same increments are used for 10 C and 20 mm of rainfall, respectively, on the ordinate. Using this scale, a strictly arid period prevails when the rainfall curve goes below the temperature curve and a humid period when the rainfall curve rises above the temperature curve.

A climatic diagram for the Veyo powerhouse is presented in Figure 5. According to this diagram the humid period of the blackbrush region extends from November through April, while the arid period extends from May through October. The mean annual temperature is 12 C with a mean annual precipitation of 300 mm. The mean number of frost free days is 155 with the last frost coming in May and the first in September. The lowest recorded temperature during the period of record was -24 C and the highest temperature 41 C.

Figure 6 represents a climatograph of the years 1958 through 1971.





- a-Station  
b-Elevation  
c-Years of record  
d-Mean annual temperature (C)  
e-Mean annual precipitation (mm)  
f-Mean daily minimum of coldest month (C)  
g-Absolute minimum (C)  
h-Mean daily maximum of hottest month (C)  
i-Absolute maximum (C)  
j-Monthly mean temperature (C)  
k-Monthly mean precipitation (mm)  
l-Months with mean daily minimum below 0 C  
m-Months with absolute minimum below 0 C  
n-Mean number of frost free days
- Arid period   
Humid period 

Figure 5 Climatic diagram representative of blackbrush region in southwestern Utah



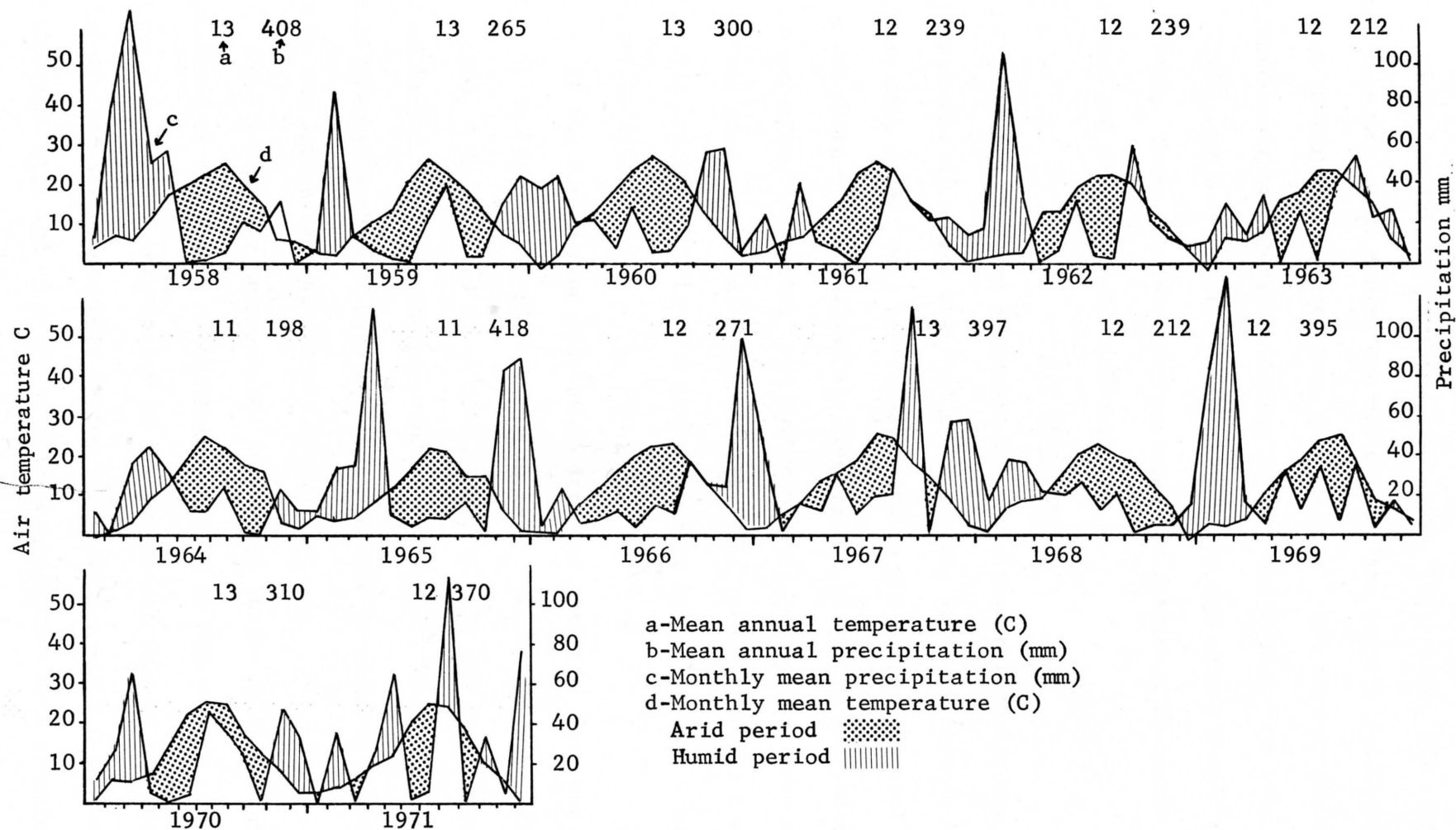


Figure 6 Climatic diagram for Veyo powerhouse representing a period of 14 years from 1958 to 1971.



Dry years are evident in 1959, 1960, 1961, 1963, 1964, and 1970. Peaks in moisture are noted during the winter and late summer. Little variation is noted in air temperatures from year to year. The three years of this study reveal heavy precipitation during January and February of 1969, a dry year in 1970, and a dry winter followed by heavy spring and summer precipitation in 1971. These precipitation patterns are reflected in variations of growth and phenology of blackbrush.

#### Air Temperatures

Climatic diagrams summarize all the climatic elements but detailed air temperature data were obtained in this study and presented in Appendix I. These data reveal very hot temperatures in the summer and cold temperatures in the winter. The maximum air temperature of 44.5 C was recorded at the juniper-blackbrush site. The number of days equaling or exceeding 38.0 C at this site was 32 in 1970 and 49 in 1971. Exceeding 40.5 C were 12 days in 1970 and 20 in 1971. The number of days exceeding 43.5 C was 2 in 1970 and 4 in 1971.

At the Joshua tree-blackbrush site the number of days exceeding 38 C was 41 in 1969, 31 in 1970 and 48 in 1971. Exceeding 40.5 C days were 9 in 1969, 8 in 1970 and 15 in 1971. Only in 1970 did the temperature exceed 43.5 C, and this was recorded on two dates. These data indicate that the juniper-blackbrush site was characterized by slightly higher temperatures than the Joshua tree-blackbrush site.

The lowest air temperature, during the period of this study, was -15.3 C recorded at the Joshua tree-blackbrush site on February 26, 1971. On this same date the low temperature at the juniper-blackbrush site was -13.6 C. The minimum air temperature during 1969-1970 was -13.6 C at the Joshua tree-blackbrush site and -9 C at the juniper-blackbrush site recorded on January

2, 1970. During the winter of 1970-1971 the low temperature was  $-14.5^{\circ}\text{C}$  at the Joshua tree-blackbrush and  $-14.2^{\circ}\text{C}$  at the juniper-blackbrush site recorded on January 7, 1971. These data indicate that the minimum temperatures for most years can be expected during the months of January or February.

High air temperatures can be expected during the months of June, July, August and September. Considerable fluctuation in temperature occurs in March and April with a warming trend occurring in May. Freezing temperatures can be expected up until the first week in May. Temperatures decrease gradually during late August and early September.

Relative humidities are rather high during the spring months then gradually decrease in June during the time that air temperatures increase. The lowest relative humidities occur during the last week in June or the first week in July. Relative humidities rise again with the advent of the summer storm period in July and August.

#### Precipitation

Precipitation data were obtained from seven different locations and ranged from 23 years of record to the three years of this study (Figure 7).

The 23 year record was obtained from the Gunlock powerhouse (Figure 7A). This station is located at an elevation of 1400 meters and is representative of the blackbrush region both in location and elevation. This station recorded an average annual precipitation of 274 mm from 1949 through 1971. The least precipitation was 93 mm recorded in 1956 and a high of 428 mm recorded in 1957.

A 13 year record obtained from the Veyo powerhouse revealed an average annual precipitation of 300 mm (Figure 7B). A B.L.M. rain gauge at Tobin Wash, which is in close proximity to the juniper-blackbrush site, showed

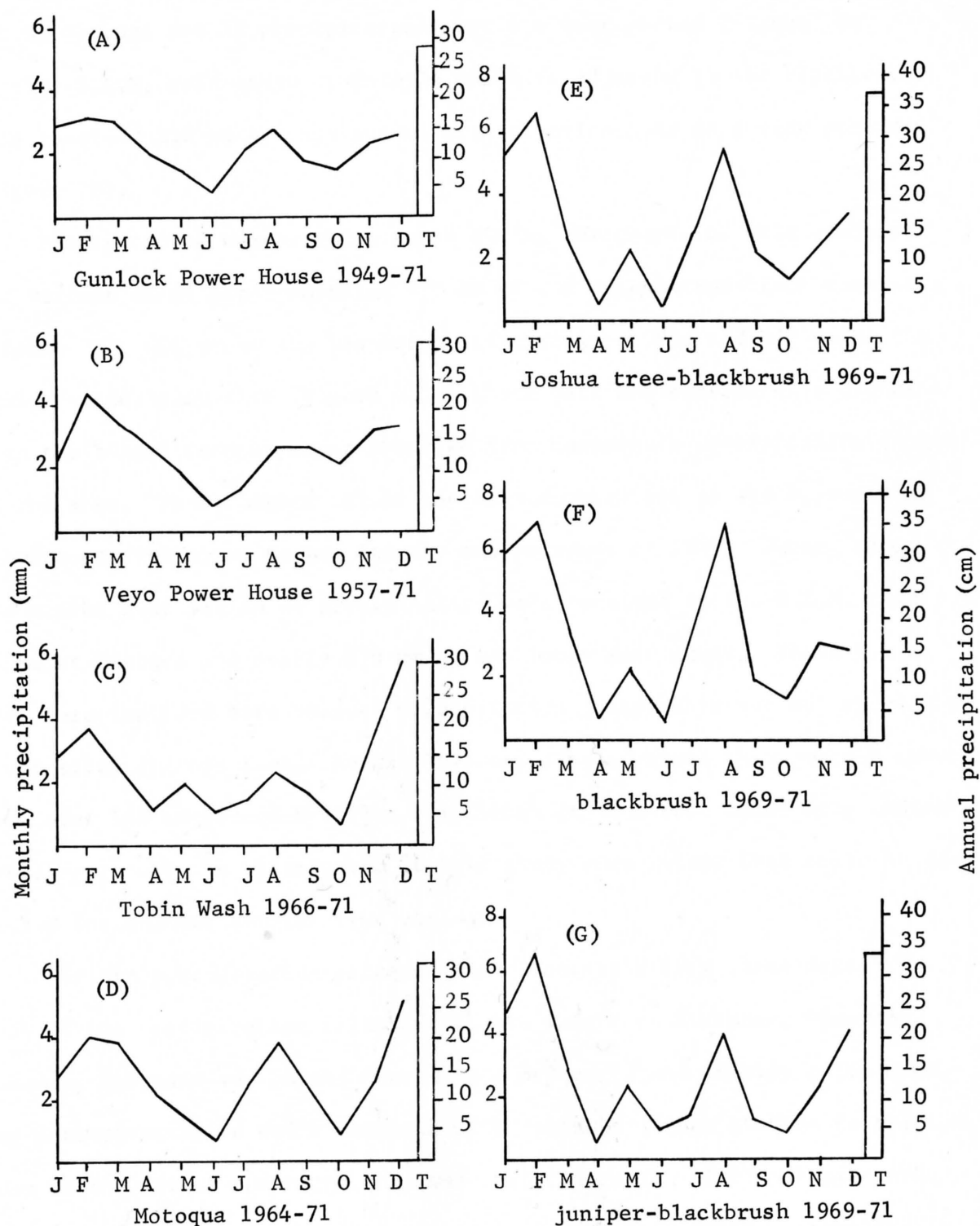


Figure 7 Precipitation measurements obtained from seven locations at or near study sites. Letter T denotes total annual precipitation.

276 mm average annual precipitation over a 6 year period (Figure 7C).

Another B.L.M. rain gauge at Motoqua which is adjacent to the blackbrush site recorded 330 mm average annual precipitation over an 8 year period (Figure 7D).

Precipitation measurements taken during the course of this study at the various study sites revealed 370 mm at the Joshua tree-blackbrush site (Figure 7E), 400 mm at the blackbrush site (Figure 7F), and 332 mm at the juniper-blackbrush site (Figure 7G). These data are considerably higher than the longer term averages obtained from comparable precipitation gauges in the area. These higher values can be accounted for by the higher than average precipitation during January and February of 1969. During those two months over 318 mm of precipitation were received at the B.L.M. rain gauge at Motoqua and nearly 279 mm at the Tobin Wash gauge. These B.L.M. data were included here because precipitation gauges were not set up at the study sites at that time. August 1971 was also a wetter than average month with over 145 mm recorded at the blackbrush study site. These data indicate, therefore, that the three years of this study were wetter than could be expected for another similar time period.

Certain precipitation patterns are discernible from these data. The bulk of the precipitation falls during the months of November, December, January, February and March. April is a dry month and usually quite warm. May precipitation is quite variable with variations from station to station. June is the driest month and the time that the growth of blackbrush ceases. Summer storms begin in July and generally reach their maximum intensity in August. The amount of September precipitation is similar to that of July, but with the storms being restricted to the early portion of the month. October is a dry month but precipitation generally increases in November

and December. Snow falls during the winter months but remains on the ground for only short periods.

### Soil Descriptions and Analyses

Distribution of blackbrush stands in the study area indicates a rather close correlation to soil types. Blackbrush is found on the upper slopes grading into creosote bush (Larrea tridentata (D.C.) Coville) at the lower elevations and pinyon-juniper at the higher elevations. Sandsage (Artemisia filifolia Torr.) is found in the sands to the exclusion of blackbrush.

Soil descriptions and analyses are presented as a means of characterizing the soils in the blackbrush area. All three study sites are located on old ridges of alluvium at approximately 1200 m sloping to the east or southeast at approximately 2 per cent. All sites are well drained, moderately permeable with slow runoff. Parent materials are mixed alluvium from limestone, gneiss, schist, sandstone, and at one site basalt. Moderate water erosion was noted at each site.

Classification of the soil at the Joshua tree-blackbrush and blackbrush site was Typic Paleorthid, loamy, mixed, thermic and shallow, and named a Cave gravelly loam, 2 to 7 per cent slopes. The juniper-blackbrush site was classified as a Pastura loam which is a member of the loamy mixed mesic "shallow" family of Ustollic Paleorthid, 0 to 10 per cent slopes. All names used here are subject to correlation. Complete profile descriptions of these soils are presented in Appendix II.

An A-C horizon sequence is found in these soils. The A<sub>1</sub> is a thin horizon of 0-7 cm in the open areas between plants and approximately twice that thick beneath the plants. A C<sub>1</sub> and C<sub>2</sub> horizon was found in all three sites with the addition of a C<sub>3</sub> at the Joshua tree-blackbrush site. A petrocalcic horizon is typical of these soils and is located at depths of 38

to 46 cm (Figure 8).

Chemical and physical analyses are presented in Table 1. The pH values range from 7.8 to 8.0 with no definite trends within the profile. Total soluble salts (ECe) range from 0.3 to 1.1 mmho/cm with the highest values under the canopy near the soil surface. Organic matter was consistently higher at the surface under the canopy and an increase was noted between the C<sub>1</sub> and the deeper horizons. Cation exchange capacity ranges from 11.0 to 15.0 milliequivalents per 100 grams with no distinct trends noted within the profile. Lime (CaCO<sub>3</sub> equivalents) increases with increasing depth to a maximum at the C<sub>2</sub> or C<sub>3</sub> horizons.

Soil textures are mainly sandy loams with a high percentage of gravel at the Joshua tree-blackbrush and blackbrush sites. The juniper-blackbrush site contains less gravel and has a finer textured C<sub>2</sub>. Loams are found in the C<sub>3</sub> of the Joshua tree-blackbrush, and the C<sub>1</sub> and C<sub>2</sub> of the blackbrush site.

Moisture percentages at several tensions, obtained from the pressure plate apparatus, are presented in Table 2. No attempt is made to infer soil moisture potential from these soil moisture values. Taylor, Evans and Kemper (1961) report that errors introduced from such inference are large.

Detailed analysis of the soils at the Joshua tree-blackbrush and the blackbrush plots revealed some interesting trends in per cent total nitrogen and available phosphorus. At the Joshua tree-blackbrush site the upper 8 cm of soil beneath the canopy contained an average of 0.072 per cent total nitrogen as compared to 0.057 per cent at the same depth in the open area between plants. At the blackbrush plot the values were 0.111 per cent and 0.055 per cent respectively (Table 3). These data show a much higher nitrogen content beneath the plants than in the open areas. There is also



Figure 8 Petrocalcic horizon typical of blackbrush soils in this area.

Table 1 Chemical and physical analysis of blackbrush soils

location and depth (cm)		pH	total soluble salts (ECe mmho/cm)	organic matter (per cent)	cation exchange capacity (m.e./100g)	lime CaCO <sub>3</sub> equiv. (%)	particle size distribution			
							sand (%)	silt (%)	clay (%)	texture
Joshua tree-blackbrush										
canopy	0-8	7.9	0.8	3.29	13.6	27.7	67	23	10	sandy loam
open	0-3	8.0	0.5	0.91	12.7	25.0	57	32	11	sandy loam
	3-9	8.0	0.4	0.57	12.0	31.9	55	32	13	sandy loam
	9-21	7.9	0.4	0.71	13.7	31.8	52	32	16	sandy loam
	21-38	8.0	0.3	0.95	13.1	32.2	48	30	22	loam
blackbrush										
canopy	0-8	7.8	1.1	5.36	14.0	15.7	66	26	8	sandy loam
open	0-3	8.0	0.6	3.34	12.4	18.6	62	29	9	sandy loam
	3-24	8.0	0.3	0.93	11.3	24.5	51	31	18	loam
	24-41	8.0	0.3	1.10	12.0	28.0	50	34	16	loam
juniper-blackbrush										
canopy	0-11	8.0	0.5	1.86	11.0	22.9	76	14	10	sandy loam
open	0-7	7.8	0.4	0.71	14.5	28.5	58	23	19	sandy loam
	7-31	8.0	0.3	0.91	14.0	32.6	56	25	19	sandy loam
	31-46	8.0	0.4	1.12	15.0	54.0	48	27	25	sandy clay



a tendency for nitrogen to decrease with increasing depth (Table 4). This trend is more pronounced beneath the canopy than in the open areas.

Table 2 Soil moisture expressed as per cent of oven dry weight of soil at several tensions.

site location and depth (cm)	tension in bars				
	1/10	1/3	1	2	15
<u>Joshua tree-blackbrush</u>					
Canopy 0-10	29.2	15.4	11.0	10.5	9.5
Open 0-10	24.8	15.1	10.8	10.4	9.4
10-20	25.6	19.2	13.4	12.2	11.6
<u>blackbrush</u>					
Canopy 0-10	23.4	13.2	11.1	8.8	7.8
Open 0-10	21.3	12.5	9.0	8.0	7.4
10-20	21.8	15.9	12.0	10.3	8.8
<u>juniper-blackbrush</u>					
Canopy 0-10	17.3	11.0	9.1	8.6	8.2
Open 0-10	18.0	17.7	14.0	12.2	11.2
10-20	26.0	20.6	15.0	14.3	13.5

Available phosphorus values are also higher in the upper 8 cm of soil beneath the canopy than in the open areas. The values at the Joshua tree-blackbrush site were 15 ppm under the canopy and 13 ppm in the open. More pronounced differences were observed at the blackbrush site with values of 25 ppm and 11 ppm respectively. Available phosphorus also decreases with increasing soil depth to approximately 30 cm at which time a slight increase is noted. This trend is found both under the canopy and in the open areas.

Table 3 Per cent total nitrogen and available phosphorus under blackbrush plants and in open areas between plants.

site	location and depth (cm)	total nitrogen (percent)	available phosphorus (ppm)
Joshua tree- blackbrush	canopy 0-8	0.072	15
	open 0-8	0.057	13
blackbrush	canopy 0-8	0.111	25
	open 0-8	0.055	11

Table 4 Per cent total nitrogen and available phosphorus in relation to soil depth.

depth of sample (cm)	total nitrogen (percent)	available phosphorus (ppm)
canopy		
0-3	0.120	32.0
3-5	0.081	14.4
5-10	0.062	9.2
10-15	0.053	5.1
15-23	0.051	4.9
23-30	0.049	3.4
30-46	0.038	7.0
open		
0-3	0.070	16.0
3-5	0.067	12.5
5-10	0.066	8.0
10-15	0.059	6.4
15-23	0.055	2.8
23-30	0.054	3.4
30-46	0.047	4.5

### Soil Moisture

Soil moisture is probably the limiting factor in the growth and survival of this desert shrub and regular measurements were taken throughout the course of this study. These readings were first taken on June 9, 1969, which was near the end of that year's growing season. All growth had stopped by June 17 of that year. It was unfortunate that soil moisture data were not available for this growing period because this was the only

year in which abundant seeds were produced. This seed production was undoubtedly a result of abundant precipitation during the winter and early spring.

Figures 9 and 10 reveal the patterns of soil moisture for all three sites during the entire years of 1970 and 1971. In 1970, the peak spring soil moisture was observed on March 21 which was one week before growth initiation was observed. In nearly all cases the soil moisture at 20 cm was greater than at 5 cm. There was a trend toward a depletion of soil moisture during the spring growing period. Precipitation was very meager during this period, with less than 4 mm falling during this time. After the predictable soil moisture depletion in June there was again a recharge in July and August with the advent of the summer storms. In general, the summer storms resulted in an increase in soil moisture at the 5 cm depth both under the canopy and in the open with a lesser increase at the 20 cm depth under the canopy and practically no increase at 20 cm in the open. Slight variations were observed between plots. Soil moisture was again low during the fall months with an increase noted during November. All growth during 1970 had ceased by June 16, with no resurgence from the summer storms.

Again in 1971, soil moisture was high during the late winter just prior to spring growth, the maximum was recorded on February 20. Soil moisture slowly decreased until approximately April 15, when spring storms resulted in a recharge of the soil moisture and three peaks were observed in April and May. These spring storms are unusual in this area and the growth rate responded to this increase in soil moisture especially from storms between May 5 and 9 which were the highest intensity storms of that month. These storms were of sufficient magnitude to recharge the soil moisture down to 20 cm which is in the zone of most abundant root biomass. Soil moisture

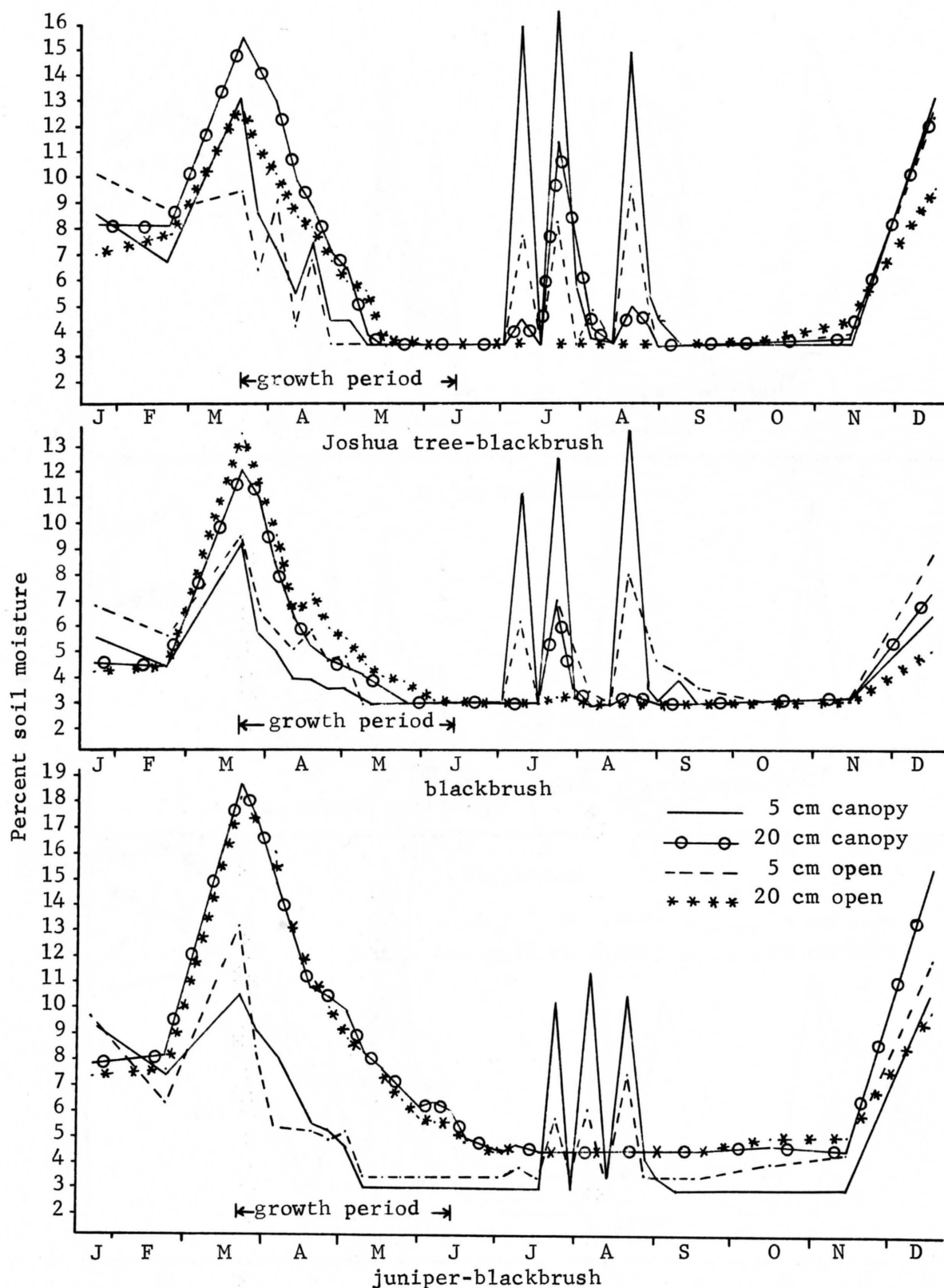


Figure 9 Seasonal trends in soil moisture during 1970 expressed as percent moisture on an oven dry weight basis.

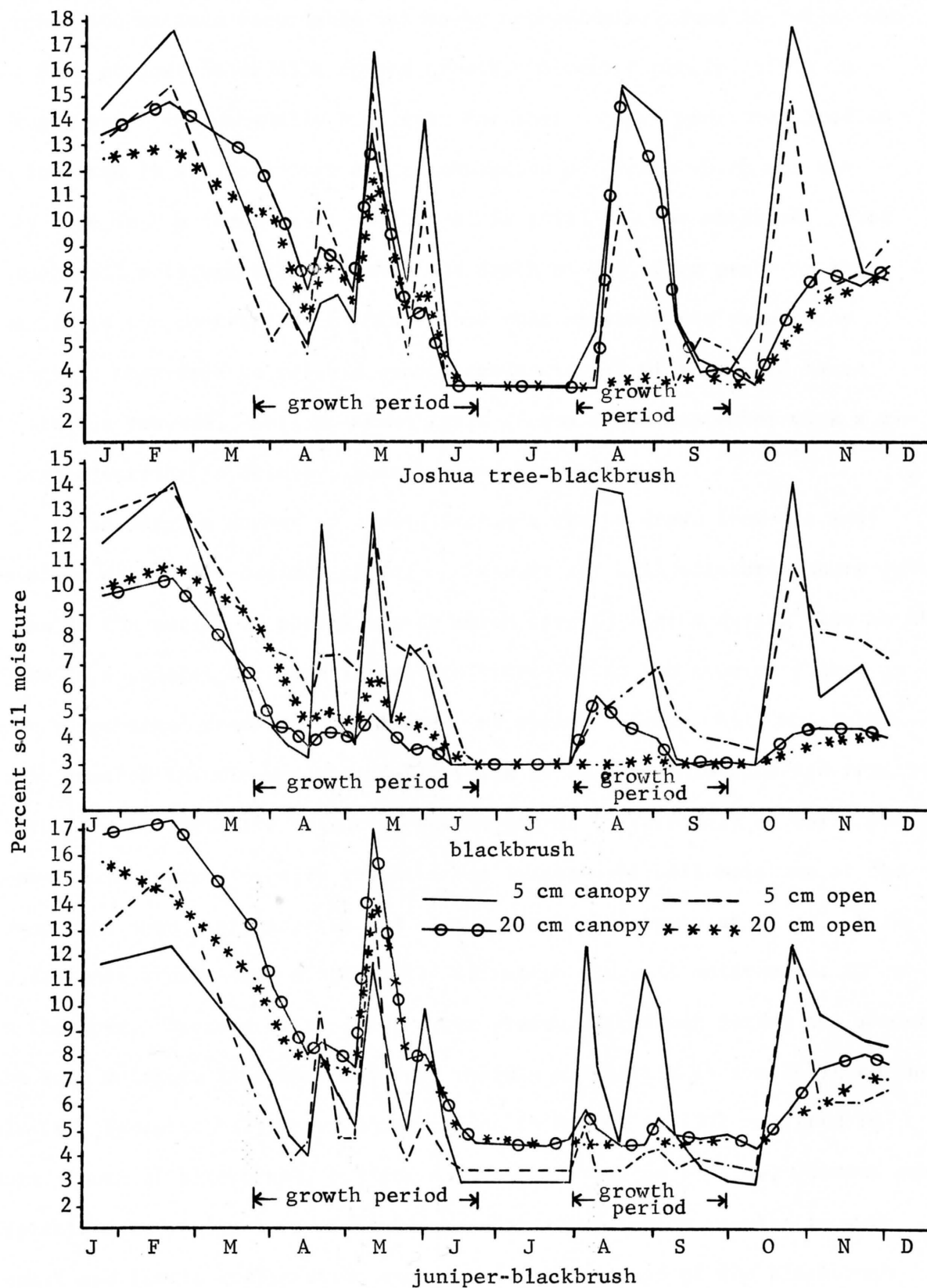


Figure 10 Seasonal trends in soil moisture during 1971 expressed as percent moisture on an oven dry weight basis.

reached its minimum recordable values by approximately June 16, which was the date of last observable spring growth. Abundant precipitation in August, which was unusually high even for that time of year, resulted in an increase in soil moisture and a resumption of growth which was the only time in the three years of this study that this was observed. Even though soil moisture did not reach the depth of the 20 cm probe in the open it is the contention of this author that moisture did reach deep enough in that area to reach a considerable biomass of roots and hence growth was resumed. Soil moisture again decreased in September with a recharge occurring in October, November and December.

In summary, a number of generalizations can be drawn from the soil moisture data. The maximum spring or late winter soil moisture occurs just prior to the period of spring growth which usually begins during late March. There is a general decrease in soil moisture during the growing season unless a recharge occurs through infrequent spring storms. Soil moisture usually reaches its minimum recordable value by early to mid-June and remains at that level until the advent of summer storms in late July or early August. These summer storms usually result in an increase of soil moisture at the canopy and open surface areas and also beneath the canopy at 20 cm. Rarely do these storms have a noticeable effect on the soil moisture at 20 cm in the open. Because of the high vapor pressure gradient during the summer, the soil moisture is evaporated very rapidly and little is available to the plants. Exceptionally heavy summer rains in August of 1971 resulted in some growth of blackbrush, but for only a short period of time. Summer precipitation is in the form of high intensity storms which results in much runoff and little infiltration except under the canopy of the blackbrush plants. The most effective water uptake by blackbrush roots appears to be

deep in the openings between the plants and little soil moisture is present in these areas except during the spring growing season.

### Soil Temperature

A plot of yearly soil temperatures for 1970 is presented in Figure 11. The 5 cm probe located in the open areas between plants is consistently warmer throughout the summer months. There is also greater variation at this location than at any of the other three. Much of the fluctuation which occurs during the spring and summer months can be accounted for by changes in the soil moisture content. The 5 cm canopy location followed the same general trend as the 5 cm open but the magnitude and degree of fluctuation was less.

Little difference was noted between the temperatures at the 20 cm depth at the two probe locations, but the open temperature was nearly always higher than the canopy location, except during the winter when the two temperatures were very similar.

Soil temperature increases were usually exhibited between February and March with the peak temperatures being reached during June or July. In general, slightly cooler summer soil temperatures were noted in August due to the wet soils. A rapid and consistent decrease in soil temperature began in early September, and continued through the fall and into the winter.

The maximum soil temperature recorded during this study occurred at the Joshua tree-blackbrush site on June 24, 1970 at the 5 cm open location. The temperature on this date was 46 C.

Winter soil temperatures were approximately 4 C with little variation between the four probe locations.

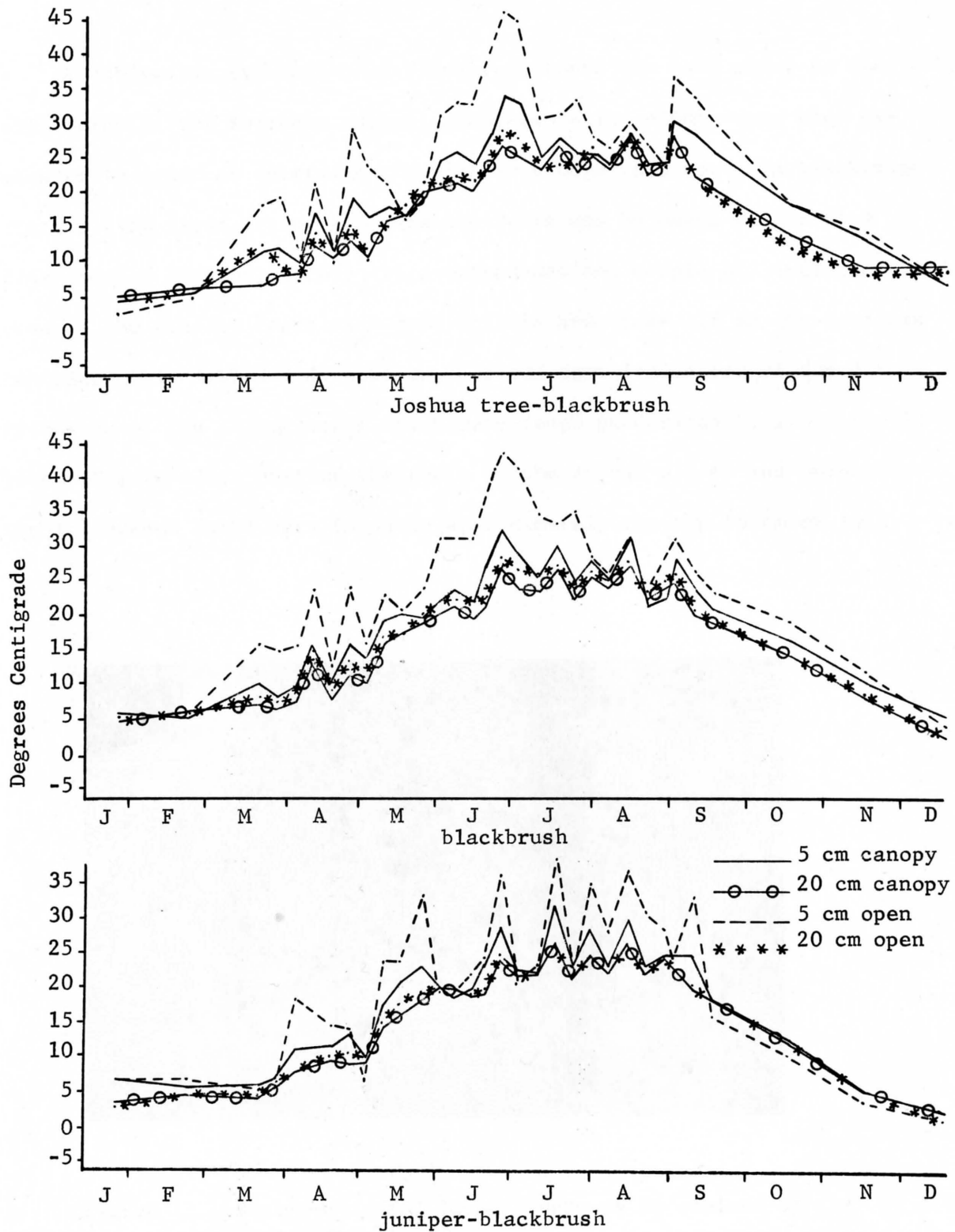


Figure 11 Seasonal trends in soil temperature for 1970.



### Root Profiles

A subjective evaluation of blackbrush roots was made prior to the installation of the moisture probes. Representative plants were then excavated in order to determine the distribution of all roots in blackbrush stands. The first attempt to excavate roots was by means of the "ice pick" method (Weaver, 1926). This method was not completely satisfactory because the smaller roots were very brittle and broke off as the soil was removed. This method did, however, provide some indication of the distribution of the larger roots which were found predominantly above the 35 cm level (Figure 12). Most of the roots of the annual plants and bulbs of the liliaceous forbs were found in approximately the top 10 cm of soil.



Figure 12    Distribution of larger roots as determined by the "ice pick" method

The petrocalcic horizon was reached at about 35 cm and most of the roots

were found above this point. Some roots do penetrate the petrocalcic horizon but only where it has been fractured. Where this horizon is layered there were often roots growing between the layers. These were fine roots growing in small compacted and strongly flattened masses; evidently the fractures provided small pockets of moisture. Shreve and Mallery (1953) referred to this layer as caliche and considered it a definite obstacle to roots. They found that roots run horizontally for as much as 3 to 5 m along the top of this layer. At the juniper-blackbrush site it was observed that large juniper roots were lying just on the surface of the petrocalcic horizon running horizontally.

It was evident that the roots of Joshua trees have very widespread root systems. Joshua tree roots were found in one excavation pit and the nearest plant was 11 m distant.

Although the ice pick method (Weaver, 1926) is useful for providing a qualitative view of a root system, it is not sufficient for quantitative measurements. In order to get a quantitative measure, the roots were excavated in known volumes of soil and root contents determined.

Several relationships are apparent from these data. The greatest concentration of roots is found directly beneath the plants in the 0-10 cm and 10-20 cm samples (Table 5). These are the large, heavy roots of the plants and probably aid little in the absorption of water. It is also apparent that the 0-10 cm depths, with the exception of the samples nearest the plants, have the least amount of roots (Table 5). Very few blackbrush roots were found at this depth with most of the roots being annuals or bulbs of the liliaceous forbs.

There appears to be a general decrease in root mass moving from the plant toward the open areas between plants (Figures 13 and 14). In one

Table 5 Grams of roots per 3000 cm<sup>3</sup> sample in relation to soil depth and distance from plant. Center of the excavated plant is located by vertical line in middle of the table.

depth cm	left totals													right totals	grand totals
0-10	33.5	2.3	2.3	1.4	1.3	0.9	25.3	291.8	182.7	3.0	1.3	1.8	1.9	482.5	516.0
10-20	104.5	4.7	4.2	5.2	7.2	13.2	70.0	48.9	14.8	15.0	9.0	5.6	4.0	97.3	201.8
20-30	76.2	8.8	13.4	11.8	12.3	14.6	15.3	9.3	10.3	8.1	7.8	5.1	3.8	44.4	120.6
30-40	41.6	3.3	7.1	5.1	9.6	8.0	7.5	10.7	9.9	5.0	7.7	7.2	3.0	43.5	85.1
		19.1	27.0	24.5	30.4	36.7	118.1	360.7	217.7	31.1	25.8	19.7	12.7		923.5

Joshua tree-blackbrush

$$\bar{x} = 6.4 \times 10^{-3} \text{ gm cm}^{-3} \text{ per sample}$$

0-10	104.4	0.8	1.8	1.3	0.8	0.7	99.0	39.4	1.2	0.8	0.5	0.6	0.5	42.6	147.4
10-20	68.4	1.0	2.9	3.5	6.8	9.6	44.6	25.9	7.1	2.0	1.9	1.9	1.6	40.4	108.8
20-30	25.9	1.8	3.0	3.8	2.6	5.1	9.6	16.9	8.0	2.3	2.4	1.0	2.5	33.1	59.0
30-40	33.4	5.0	6.7	5.5	4.2	7.8	4.2	4.6	6.1	9.3	4.0	1.8	6.3	32.1	65.5
		8.6	14.4	14.1	14.4	23.2	157.4	86.8	22.4	14.4	8.8	5.3	10.9		380.3

blackbrush

$$\bar{x} = 2.6 \times 10^{-3} \text{ gm cm}^{-3} \text{ per sample}$$

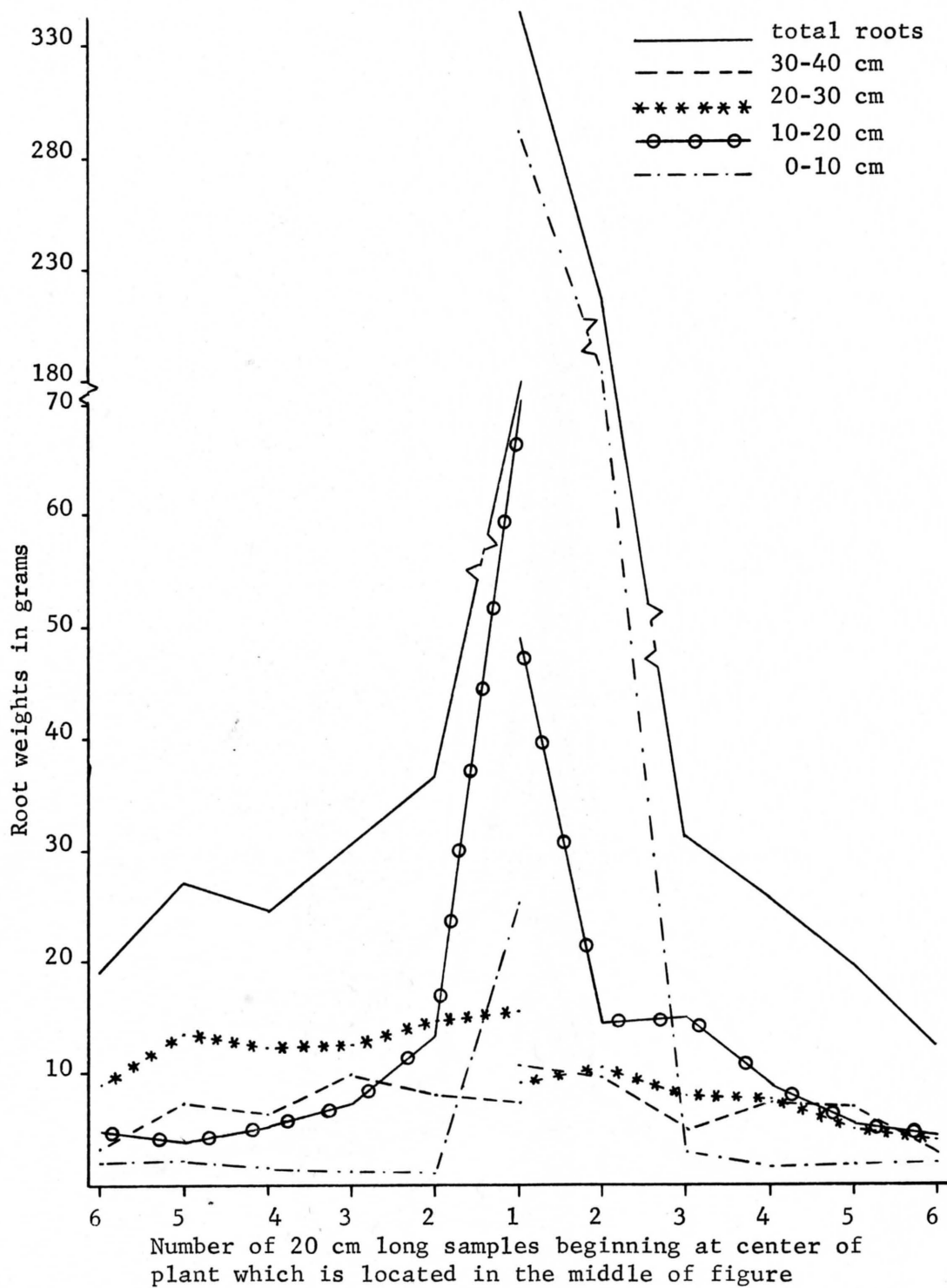


Figure 13 Root distribution in relation to distance from plant and depth of soil at the Joshua tree-blackbrush site.

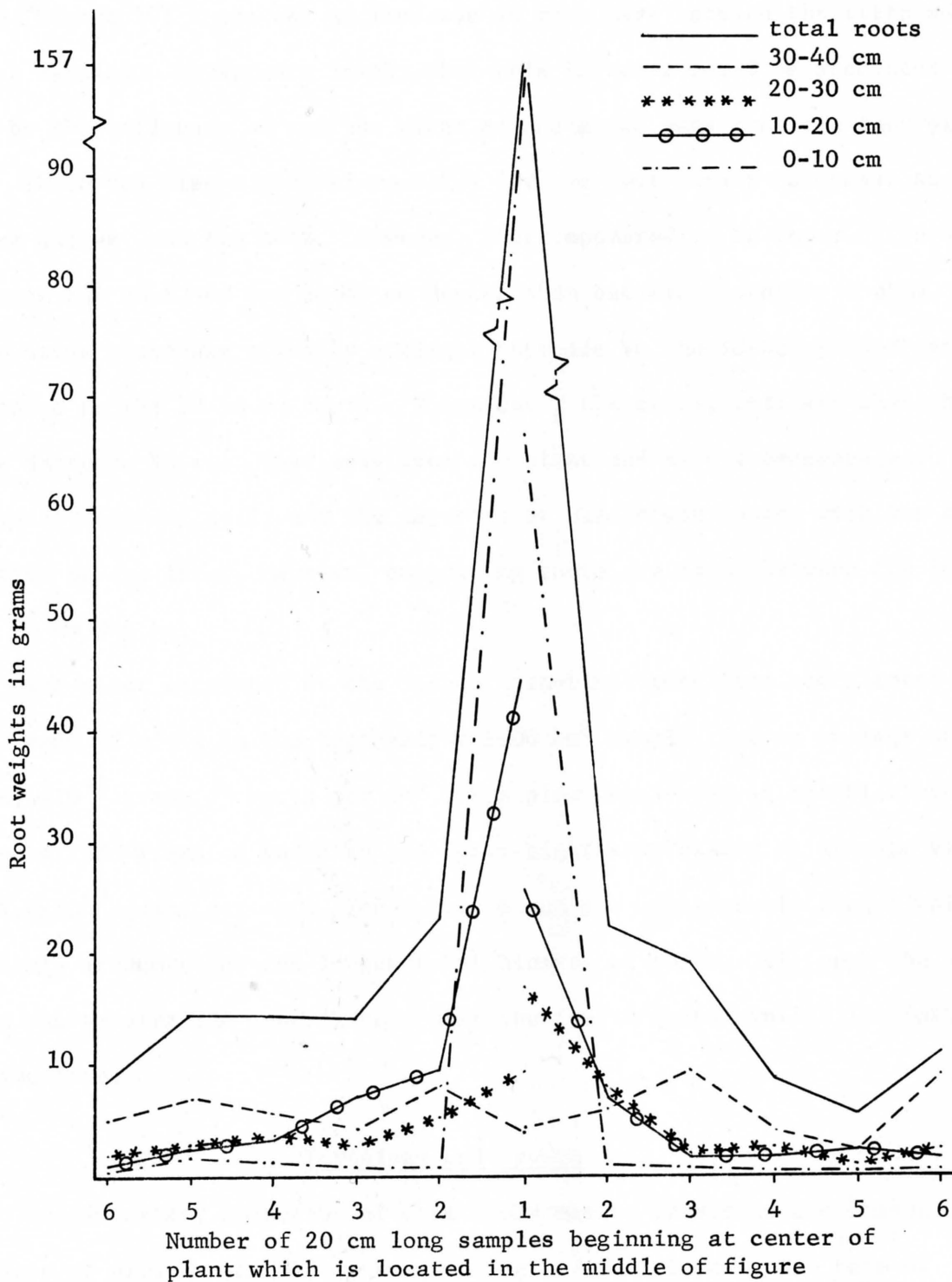


Figure 14 Root distribution in relation to distance from plant and depth of soil at the blackbrush site.

case (Figure 14) there was an increase in root mass between the fifth and sixth samples. It appears likely that this increase could be accounted for by the influence of another plant as one moved away from the test plant.

There was also a general tendency for the root mass to decrease as one moves deeper into the soil. However, there appeared to be fewer differences between the 20-30 cm and 30-40 cm depths than between the other depths. In some cases there was actually a slight increase in the 30-40 cm depth as compared to the 20-30 cm depth. These data, therefore, indicate that there is a decrease in root mass away from the plant and also a decrease with increasing depth of soil, and the majority of blackbrush roots, with the exception of the large, massive, supporting roots are found between the 10 and 30 cm depths.

The plant excavated at the Joshua tree-blackbrush site had a total of 924 grams of roots in the forty-eight 3000 cm<sup>3</sup> samples for an average value of  $6.4 \times 10^{-3}$  grams of roots per cm<sup>3</sup>. The plant excavated at the blackbrush site had 380 grams of roots in the forty-eight samples for an average value of  $2.6 \times 10^{-3}$  grams per cm<sup>3</sup>. The former plant was considerably larger which probably accounts for the larger total biomass of roots. Although the biomass was greater the general root distribution is quite similar for both excavations.

### Phenology and Growth

One important objective of this study was to determine the season or seasons of growth and follow the phenology of the plants. The rate of growth and phenology from all three study sites are combined for each year and presented in Figures 15, 16, and 17. This procedure simplified the presentation of results. The growth rates from each site were plotted separately in 1969 and it was apparent that one graph of the combined sites was

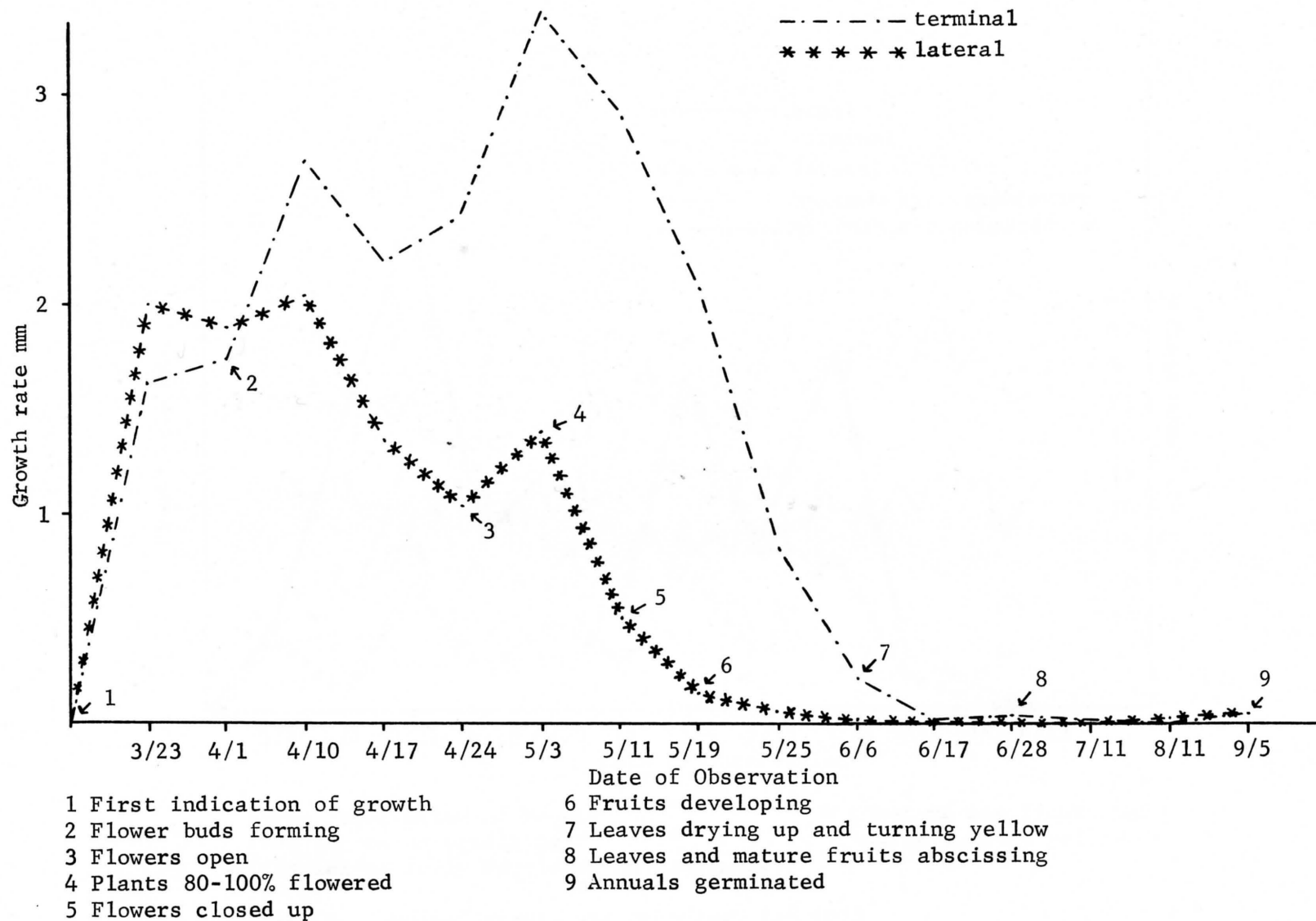


Figure 15 Combined growth and phenology for 1969

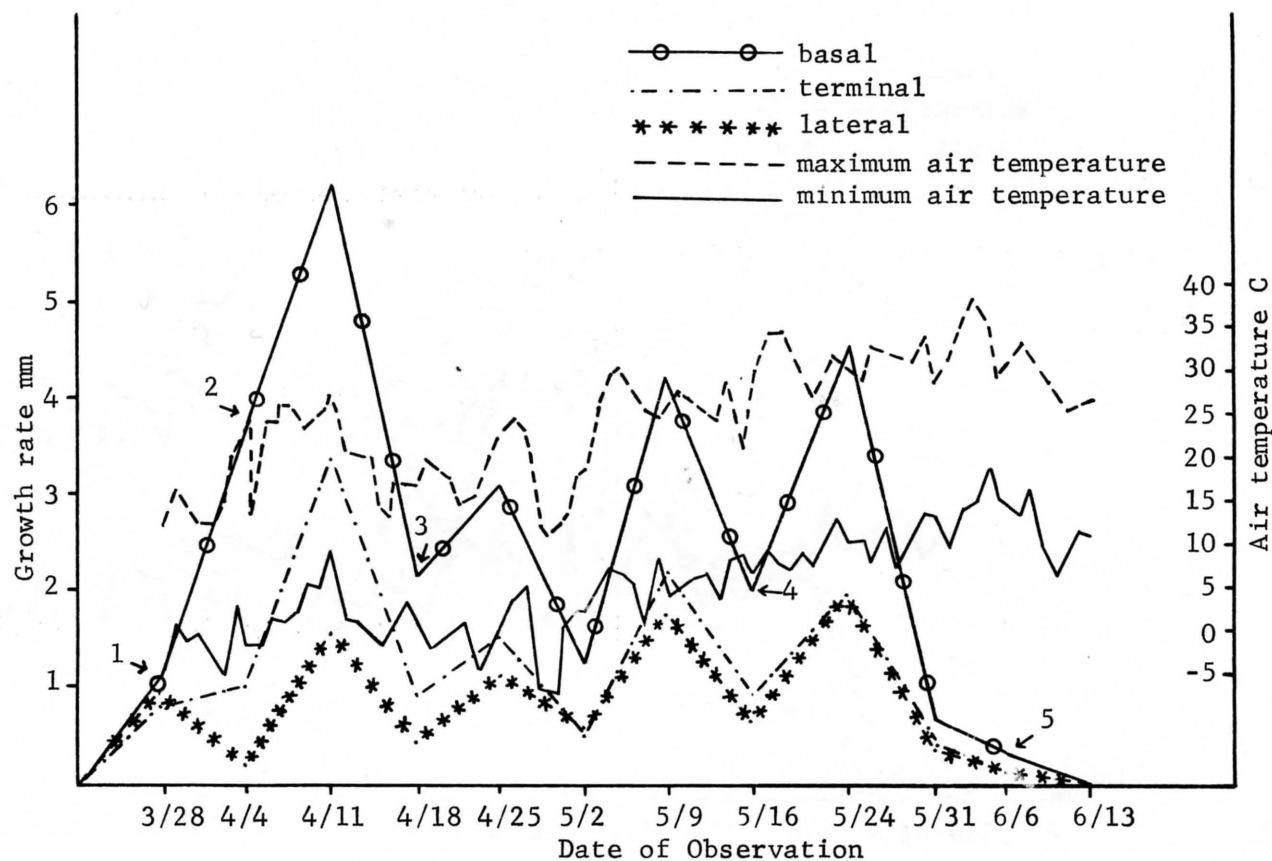
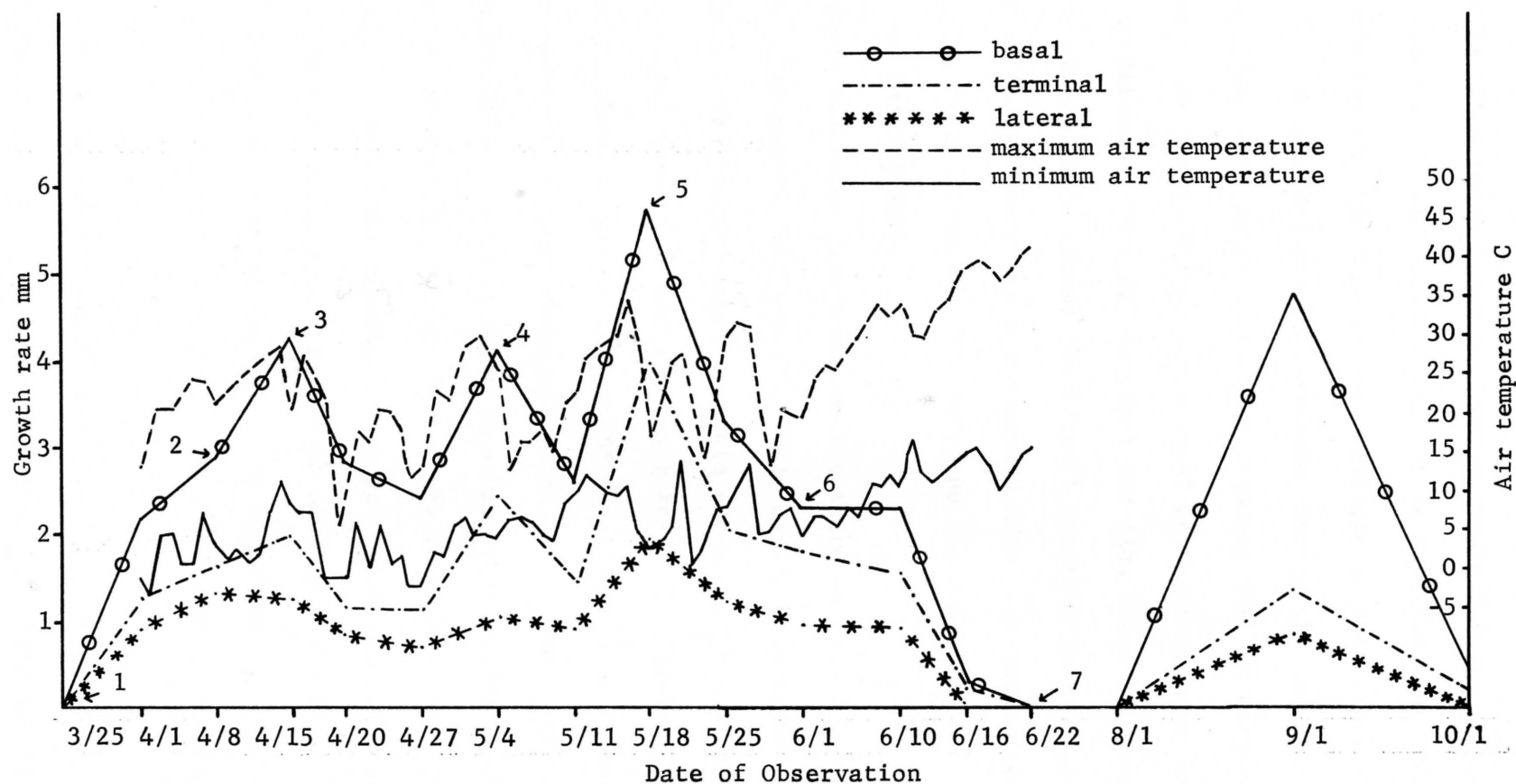


Figure 16 Combined growth and phenology for 1970





1 First indication of growth  
 2 "Brush beat" plants sprouting  
 3 Flower buds forming  
 4 Flowers open

5 Flowers closing up  
 6 All flowers closed  
 7 Growth ceased

Figure 17 Combined growth and phenology for 1971

representative of each individual site.

Figure 18 illustrates the total yearly growth for the terminal, lateral and basal branches for each study site. It is apparent that the growth of the basal branches exceeds that of the terminals or the laterals, and that the growth of the terminal branches exceeds that of the laterals. Though not apparent from these data, there is a tendency for the terminal branches to die after a few years, dry up for several centimeters back from the tip and become spinescent. When the terminal bud dies there is a suppression of apical dominance which allows the lateral branches to develop. This development of the laterals has a pronounced effect on compacting the plants and aids in the formation of the round characteristic of the plant referred to by Knapp (1965).

Blackbrush initiated growth either the third or fourth week in March of each year (Figures 15, 16, and 17). Only during 1969 was there sufficient flower development to make accurate and meaningful phenological determinations and these data are the basis for the following discussion.

Two weeks following growth initiation the flower buds began to form and after 5 weeks the flowers were fully open. The flower buds form at the tips of the terminal or lateral branches and once the flower is fully developed no further elongation occurs. By 6 weeks the plants were 80% to 100% flowered and by 7 weeks the flowers had closed, with the calyx surrounding the pistil, and the fruits were starting to develop. The older, outermost leaves were drying out and turning yellow by approximately the second week in June. The second week in July found the abscission of leaves and mature fruits.

Growth of blackbrush is usually restricted to the period of late March through mid June. This was the pattern exhibited in 1969 and 1970. How-

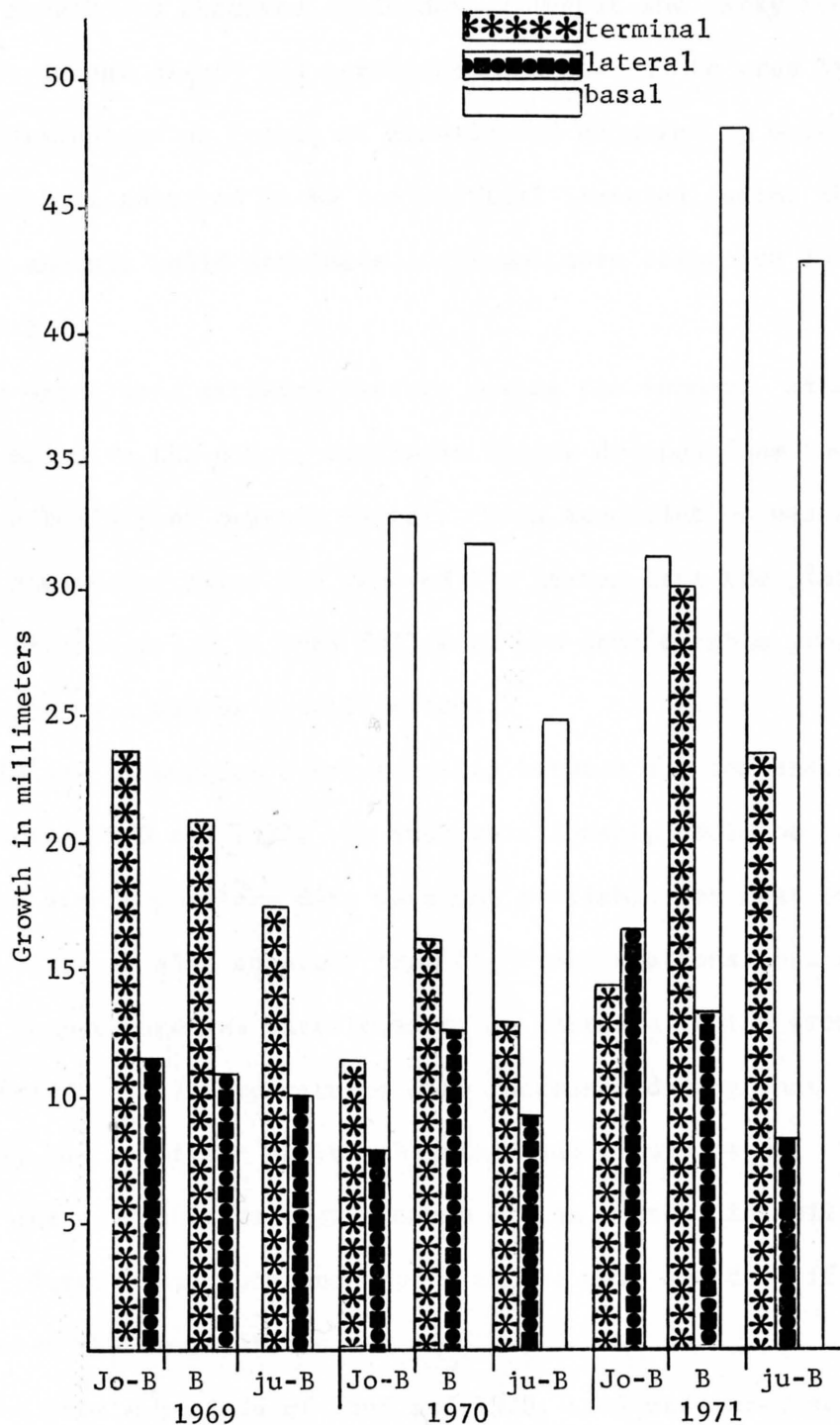


Figure 18 Average annual growth of terminal, lateral, and basal branches for 1969, 1970 and 1971 at the Joshua tree-blackbrush (Jo-B), blackbrush (B), and juniper-blackbrush (ju-B) sites.

ever, in 1971 growth was observed again during August and early September.

Understory annual plants had germinated and started to grow by October 1969, but no germination or growth of annuals had occurred by November 1970. Soil moisture appeared to be the critical limiting factor that determined when the annuals would germinate, soil moisture being too low in the fall of 1970.

Leaf drop was a very striking feature during the summer. After growth had ceased in mid June the older, outermost leaves dropped from the plants causing a large buildup of organic matter. This accumulation was most pronounced after the summer rains had removed the leaves from the plants. The greatest leaf drop occurred in 1969 following the considerable growth which resulted from abundant winter precipitation.

Figures 16 and 17 suggest a relationship between air temperatures and growth rate during 1970 and 1971. No such relationship could be established in 1969 because air temperature data were not available for most of that growth period. It was also apparent from field observations that an increase in air temperature was paralleled by an increase in the growth rate during that period. Soil temperatures also increased during that period and undoubtedly had an effect on the phenology and growth rates. These relationships are difficult to plot because of the changes in soil temperatures at different locations and depths in the soil and the different times of day when the temperatures are read.

During the growth periods of 1969 and 1970, soil moisture, at least at the 20 cm depths, was decreasing. Growth rates fluctuated at this same time and exhibited a relationship with changes in air and soil temperatures. A different pattern of soil moisture was evident during the growth period of 1971. Storms during May replenished the soil moisture and undoubtedly

had a considerable effect on the rapid growth rate increase evident during the period May 11 to May 18 (Figure 17). Over 100 mm of precipitation received in August of 1971 resulted in a resumption of growth not evident during the preceding two summers. This, without doubt, was attributable to soil moisture. Wallace and Romney (1972) reported this same phenomenon in 1967 and 1968 at the Nevada Test Site and indicated that the summer dormancy of blackbrush is a result of low soil moisture rather than high temperatures.

The increase in soil moisture during May of 1971, probably accounts for the production of flowers in 1971 which were very scarce in 1970. The abundant soil moisture during the spring of 1969 produced flowers in such abundance as is seldom seen in that country.

#### Seed Germination

Seed germination was higher for the stratified seeds with or without light when compared with the control group. Analysis of variance revealed differences significant at the 1 per cent level of probability when treatments were compared. No other statistically significant differences were found either among sites, dates of seed collection, or interactions among treatments, site locations or dates of collection.

Only the blackbrush plot revealed differences significant at the 1 per cent level of probability when treatments were compared. No significant differences were noted between dates or treatment date interactions. No statistically significant differences were found between treatments, dates of seed collection, or interactions for either the Joshua tree-blackbrush, or juniper-blackbrush seed collections.

Table 6 shows a generally lower germination rate for the seeds in the control groups compared to either of the treatments. One exception to this

Table 6 Seed germination percentages as a function of site, treatment and date of collection.

date of collection:			
location	treatment	date of seed collection	percent germination
<u>Joshua tree-blackbrush</u>			
	stratified light	June	93.4
		July	95.7
	stratified dark	June	95.0
		July	96.9
	control	June	72.2
		July	94.5
<u>blackbrush</u>			
	stratified light	June	96.9
		July	95.9
	stratified dark	June	95.9
		July	96.8
	control	June	83.0
		July	88.1
<u>juniper-blackbrush</u>			
	stratified light	June	93.7
		July	100.0
	stratified dark	June	91.2
		July	99.0
	control	June	86.6
		July	77.8

observation is the seed collected in July from the Joshua tree-blackbrush site.

Germination was very rapid for the stratified seeds exposed to light, but there was a day or two delay in the germination of the dark stratified seeds. The control group was slow to germinate and a period of 5 days was required in the growth chamber before any of these seeds germinated and 8 days before any meaningful germination occurred (Figure 19). Even after germination was well under way it was apparent that the slope of the control germination curve was less than for either of the stratified samples. It is important to note that the nighttime temperature of 4 C used in this experiment is the temperature required for the germination of blackbrush seeds as was determined by Wallace, Romney and Ashcroft (1970). These data indicate, therefore, that a period of approximately one week at 4 C is required for germination of these seeds.

Radicles of blackbrush seedlings germinated on agar-agar are devoid of root hairs, but they do have a bristly appearance near the seed which is visible only with a hand lens. Emergence of the radicle is from the narrow, bent portion of the seed. Fungi were evident on the cultures but did not appear to have an appreciable effect on seed viability or seedling survival. The stems, roots and lower surfaces of the cotyledons exposed to light contained a red pigment thought to be anthocyanin. The etiolated seedlings contained no chlorophyll or red pigments.

### Seedling Survival

One of the most obvious features of the blackbrush stands is the paucity of seedlings. In many stands seedlings are almost completely lacking and in others they are very scarce. The lack of seedlings is also striking when one views blackbrush stands that have been burned. A

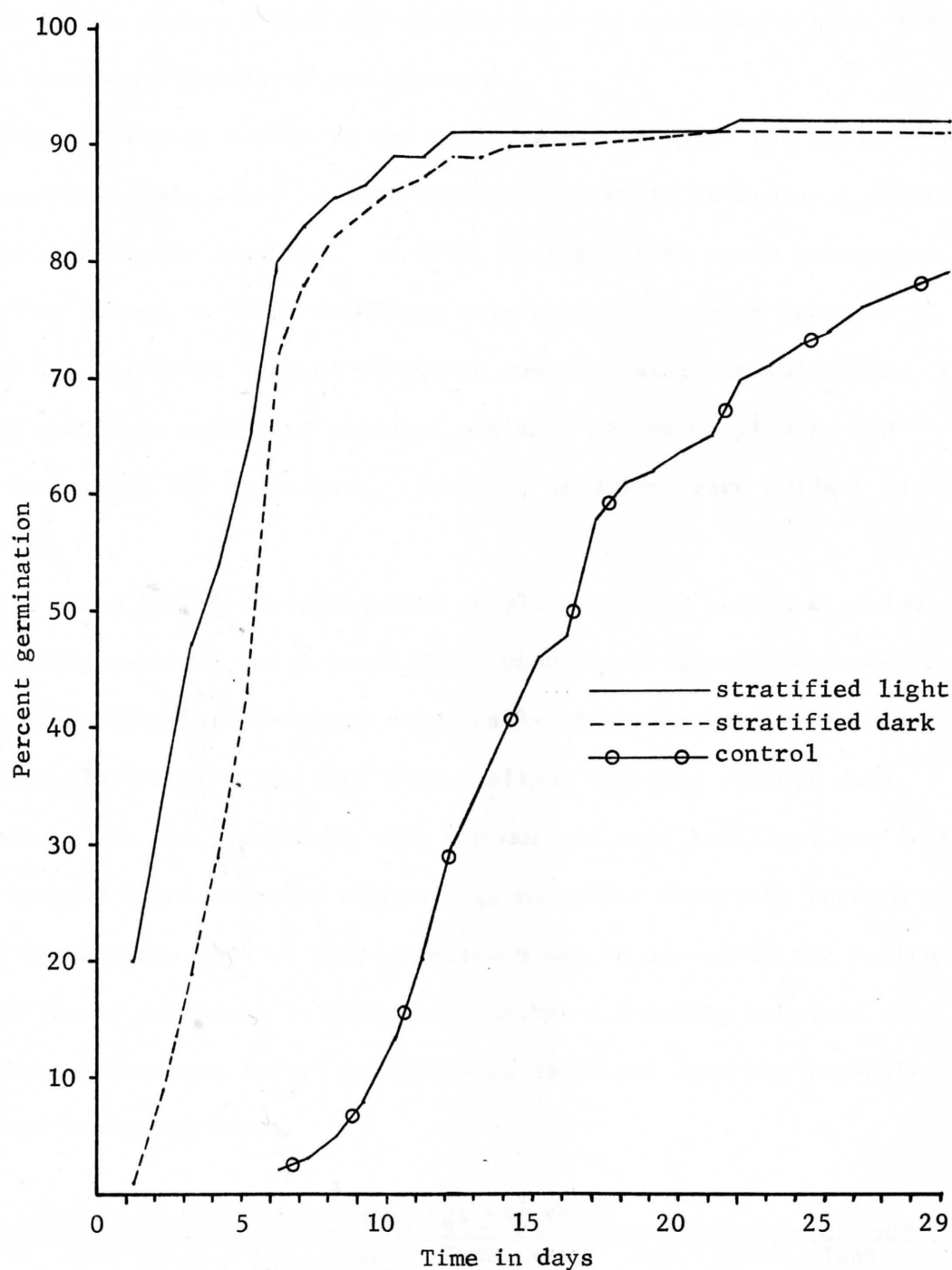


Figure 19 Graph showing the effect of treatment on seed germination as a function of time. Combined data from all three study sites.



number of common desert shrubs and annuals come in following a burn, but very few blackbrush seedlings are apparent.

During the winter months it was not possible to visit the study sites at frequent intervals, thus presenting difficulties in determining exactly when seed germination occurred. In 1969, no blackbrush seeds germinated at the study sites; in 1970, seedlings were apparent between February 21 and March 21, the exact time of emergence was impossible to establish. By March 21, seedlings were very abundant and many of the cotyledons had already been eaten off by rodents. In 1971, seedlings were evident by February 20.

Table 7 and Figure 20 reveal that seedling numbers remain at a low and relatively constant level until March when there is seedling emergence. By June this number had decreased drastically at the Joshua tree-blackbrush and juniper-blackbrush sites with only a slight decrease between June and December. At the blackbrush site the mortality of seedlings was less drastic between March and June with a high mortality occurring between June and September. Part of this phenomenon can be accounted for by the fact that it was difficult to determine whether a seedling was dead or merely dormant, and the actual loss between March and June was probably higher than indicated here.

Table 7 Number of blackbrush seedlings per 40 m<sup>2</sup>

site	June 69	Sept. 69	Dec. 69	March 70	June 70	Sept. 70	Dec. 70	March 71	June 71
Joshua tree- blackbrush	8	8	2	124	3	1	1	3	1
blackbrush	29	29	28	499	246	48	36	158	41
juniper- blackbrush	1	1	1	384	5	3	3	4	3

Although practically no flowers or seeds were produced in 1970, there

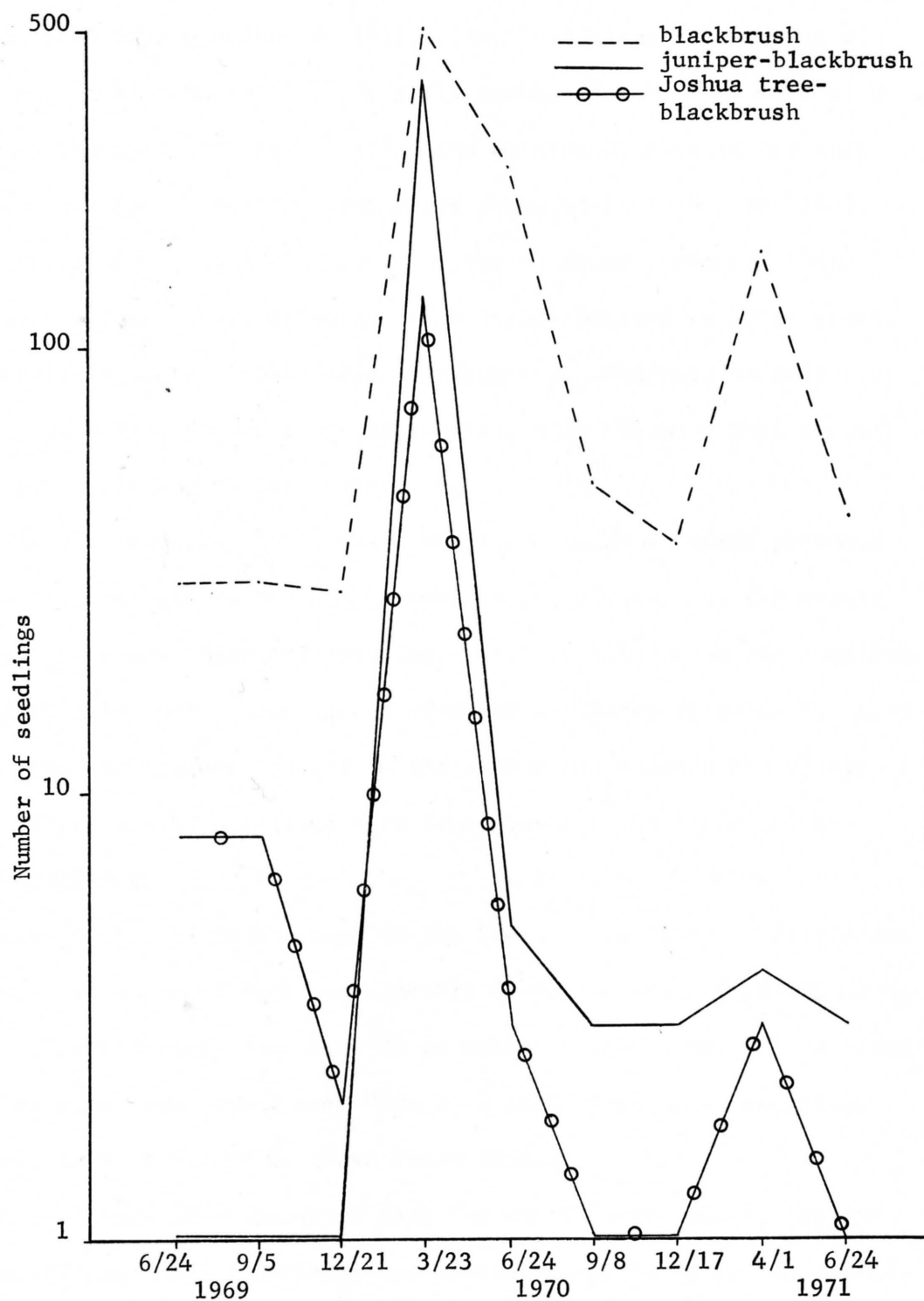


Figure 20 Number of blackbrush seedlings in relation to season of year and site.

were still seedlings emerging in 1971. These seedlings were scarce at the Joshua tree-blackbrush site. A small number of seedlings were also observed in the spring of 1972. It is the opinion of this author that these seedlings had originated from seeds produced in 1969. The 1972 seedlings were not typical of those emerging in other years and their morphology was drastically different from those observed in other years. It was difficult to recognize these as blackbrush seedlings because the cotyledons were long linear structures rather than the more oval shape of the typical blackbrush cotyledon.

During the summer of 1969, there was a profusion of seeds produced which when mature fell to the ground beneath the plants. As the summer progressed the seeds began disappearing. In the winter when the seedlings emerged they were coming from caches of seeds collected by rodents. Many of these seed caches were located in the open areas between the plants and more of the single seedlings were found beneath the canopy of the established plants.

Rodents inflicted much damage to the emerging seedlings. Cotyledons were soon eaten and seedlings consequently died. Rodent and rabbit damage was also of considerable detriment to established seedlings. Flash floods and soil erosion also caused much damage to seedlings. Many seedlings were washed away or buried by these flash floods.

Most seedlings never survived past the cotyledonary stage. As previously mentioned, rodent activity and erosion contributed to the mortality, but the lack of soil moisture was probably the single most important factor limiting seedling survival. Seedlings become established during the period of most rapid growth of annuals and competition for moisture plus the rapid depletion of soil moisture near the surface probably accounts

for the high mortality. In practically no cases did entire clusters or caches of seedlings survive the spring growth period. One or two seedlings from these groups may have survived but most died. In some cases, if the seedlings were able to produce true leaves, there was a fairly good chance of survival. Summer rains appeared to aid in the survival of seedlings that had developed true leaves. These seedlings looked vigorous when observed in September.

Desert almond (Prunus fasciculata (Torr.) Gray) seedlings appeared to have a greater ability to survive in this environment and grew much more rapidly than did the blackbrush seedlings. This early rapid growth probably helps explain the fast invasion of desert almond onto burned areas.

Seedling survival was very low at the Joshua tree-blackbrush and juniper-blackbrush sites (Table 7). When the seedling transects were first read in June, 1969, there were eight blackbrush seedlings in the eight 5 m<sup>2</sup> seedling transects at the Joshua tree-blackbrush site and only one at the juniper-blackbrush site. When the transects were last read in June, 1971, only one seedling had survived at the Joshua tree-blackbrush site. The survivor had germinated in the winter of 1971. None of the older seedlings which were fairly good-sized seedlings had survived and their demise was due primarily to destruction by rabbits or rodents. At the juniper-blackbrush site only three seedlings were alive in June, 1971. Two of these had germinated that winter and the other was the older seedling.

At the blackbrush site more seedlings were present at all times and survival was much better. Of the original 29 seedlings found in June, 1969, 13 survived the entire period of this study. Again the loss of the older seedlings was attributed to rodent or rabbit activity. Eight of the

seedlings germinating in the winter of 1970 and 20 of those germinating in 1971 survived until June, 1971.

The percent seedling survival between March and June 1970 during the time of maximum seed germination was 2.4% for the Joshua tree-blackbrush site, 1.0% for the juniper-blackbrush site, and 62.6% for the blackbrush site. Germination was also rather high in March, 1971 at the blackbrush plot which had a seedling survival percent of 14.9% when observed in June.

At the time of maximum seedling density in March of 1970, there were 3.1 seedlings per m<sup>2</sup> at the Joshua tree-blackbrush site, 9.6 at the juniper-blackbrush site and 11.9 at the blackbrush site.

#### Understory Herbaceous Plants and Blackbrush Cover

The general overview of blackbrush stands is a monotonous physiognomy because of the paucity of other shrubs. However, many annuals and some herbaceous perennials are found in the understory vegetation. Density, frequency and average height of herbaceous understory plants are presented by year and site location in Table 8. Clearly there is a dearth of herbaceous plants at the juniper-blackbrush plot. Very few species were present and the density and frequency of all species was low. The majority of the annuals were found at the Joshua tree-blackbrush and the blackbrush sites.

The dominant herbaceous species is foxtail chess (Bromus rubens L.) which consistently exhibits the greatest density and frequency. Beatley (1966) reported foxtail chess as being abundant in the undisturbed stands of blackbrush in Nevada. She reported that it is frequently the dominant annual growing in greatest numbers under shrubs and especially at the periphery of the shrub canopies. It often exhibits more vigorous vege-

Table 8 Density, frequency, and average height of understory herbaceous vegetation.

	Joshua tree-blackbrush									blackbrush								
	Density			Frequency			Average height (cm)			Density			Frequency					
	(plants/0.1m <sup>2</sup> )									(plants/0.1m <sup>2</sup> )								
	1969	1970	1971	1969	1970	1971	1969	1970	1971	1969	1970	1971	1969	1970	1971	1969	1970	1971
<i>Calochortus flexuosus</i> Wats.	0.54	0.10	0.46	35	7	26	24.2	6.8	9.2	0.60	0.06	0.30	41	5	21			
<i>Cryptantha pterocarya</i> (Torr.) Greene	3.53	0.14	1.23	67	13	27	11.1	3.2	6.9	5.55	0.06	0.78	60	5	34			
<i>Phacelia fremontii</i> Torr.	0.89		0.42	35		16	6.0		6.2	0.06			5					
<i>Navarretia propinqua</i> Suksd.	0.39	0.07		21	4	0	1.7	7.5		0.60		0.15	22		10			
<i>Androstaphyllum breviflorum</i> Wats.	0.74	0.01	0.03	30	1	2	13.9	5.0	4.5	0.55	0.03	0.38	27	2	20			
<i>Vulpia octoflora</i> (Walt.) Rydb.	0.22	0.46	0.06	10	14	4	7.3	3.0	4.5	0.14	1.42	0.35	9	23	10			
<i>Poa bigelovii</i> Vasey & Scribn.	0.04	0.06	0.01	3	5	1	9.3	5.8	2.0		0.02	0.01		2	1			
<i>Bromus rubens</i> L.	36.61	34.49	8.81	98	91	62	11.7	7.5	9.7	38.84	8.93	4.89	92	75	56			
<i>Erodium cicutarium</i> (L.) L'Her.	4.77	3.84	1.05	55	61	27	4.4	2.5	3.2	0.84	0.69	0.35	23	19	8			
<i>Bromus tectorum</i> L.		0.01	0.35		1	6		12.0	13.3		3.82	8.47		56	58			
<i>Eriophyllum wallacei</i> Gray	0.73	0.02	0.09	38	2	8	3.4	1.5	2.6	0.27	0.02	0.14	13	1	8			
<i>Stephanomeria parryi</i> Gray	0.24	0.09	0.37	8	7	13	16.8	5.2	4.3	0.02			2					
<i>Mimulus parryi</i> Gray	0.86	0.03		28	3		3.2	5.0		0.50			24					
<i>Plantago purshii</i> Roem. & Schult.	0.04		0.02	1		1	7.0		3.5	0.86	1.05	0.12	25	29	9			
<i>Mentzelia albicaulis</i> Dougl.	0.17		0.01	8		1	5.8		4.0	0.12		0.01	8		1			
<i>Astragalus geyeri</i> Gray	0.07	0.12	0.08	6	12	8	6.1	3.3	2.3		0.07			7				
<i>Chorizanthe thurberi</i> (Gray) Wats.										0.54	0.04	0.31	21	4	17			
<i>Eriastrum diffusum</i> (Gray) Mason										0.22	0.01	0.04	14	1	3			
<i>Nama demissum</i> Gray	0.07			2			1.5			0.33			17					
<i>Lupinus brevicaulis</i> Wats.	0.05			5			3.9			0.06			6					
<i>Langloisia setosissima</i> (Torr. & Gray) Greene										0.66	0.02	0.02	24	2	2			
<i>Delphinium amabile</i> Tidestrom	0.10			8			16.3											
<i>Mirabilis multiflora</i> (Torr.) Gray	0.02			1			45.0											
<i>Eschscholtzia multiflora</i> Wats.	0.01			1			10.0											
other	0.01	0.19	0.11	1	5	4	32.0	6.0	11.4		0.21	0.12		7	6			

Table 8 Continued

	<u>blackbrush (Cont.)</u>						<u>juniper-blackbrush</u>					
	Average			Density			Frequency			Average		
	height (cm)			(plants/0.1m <sup>2</sup> )						height (cm)		
	1969	1970	1971	1969	1970	1971	1969	1970	1971	1969	1970	1971
<i>Calochortus flexuosus</i> Wats.	21.2	5.2	10.3	0.05	0.02	0.08	5	2	8	20.8	26.0	13.7
<i>Cryptantha pterocarya</i> (Torr.) Greene	9.2	5.9	3.8	0.14		0.02	7		2	6.3		5.0
<i>Phacelia fremontii</i> Torr.	7.1			0.14		0.06	7		6	4.2		4.4
<i>Navarretia propinqua</i> Suksd.	2.1		4.7	0.02		0.01	2		1	2.0		2.0
<i>Androstephium breviflorum</i> Wats.	11.9	9.0	9.0			0.01			1			30.0
<i>Vulpia octoflora</i> (Walt.) Rydb.	2.2	3.1	5.7			0.04			4			3.0
<i>Poa bigelovii</i> Vasey & Scribn.		4.0	3.0	0.01			1			5.0		
<i>Bromus rubens</i> L.	11.7	9.6	7.6									
<i>Erodium cicutarium</i> (L.) L'Her.	3.5	2.6	2.6									
<i>Bromus tectorum</i> L.		13.4	10.9									
<i>Eriophyllum wallacei</i> Gray	3.9	2.0	2.9									
<i>Stephanomeria parryi</i> Gray	14.5											
<i>Mimulus parryi</i> Gray	4.0											
<i>Plantago purshii</i> Roem. & Schult.	3.0	2.7	2.7									
<i>Mentzelia albicaulis</i> Dougl.	7.8		2.0									
<i>Astragalus geyeri</i> Gray		2.2										
<i>Chorizanthe thurberi</i> (Gray) Wats.	5.0	3.5	2.8	0.07			6			4.0		
<i>Eriastrum diffusum</i> (Gray) Mason	4.2	1.0	5.6	0.01			1			10.0		
<i>Nama demissum</i> Gray	2.0											
<i>Lupinus brevicaulis</i> Wats.	5.0											
<i>Langloisia setosissima</i> (Torr. & Gray) Greene	2.7	1.5	3.0									
<i>Delphinium amabile</i> Tidestrom												
<i>Mirabilis multiflora</i> (Torr.) Gray												
<i>Eschscholtzia multiflora</i> Wats.												
other		6.4	3.5			0.01			1			2.0

tative and reproductive growth and occurs in denser stands on disturbed sites, especially where shrubs have been destroyed by fire. Although fire will spread easily in blackbrush due to its tinder-like nature and close spacing, the presence of foxtail chess in undisturbed communities has doubtlessly enhanced the potential for the start and spread of fires. Other prominent annuals are Cryptantha pterocarya (Torr.) Greene and Erodium cicutarium L. Livestockmen using this area refer to Erodium as one of the better forage plants of this type and they rely on it for a considerable amount of forage. Unfortunately the productivity of this species fluctuates greatly with precipitation and even though it may exhibit a relatively high density and frequency the height of the plant is small (Approximately 3 cm). Bromus tectorum L. is another common annual and was found to be most abundant in the blackbrush plot. However, B. tectorum is not nearly as common as B. rubens L. No B. tectorum L. was recorded in 1969 because the plots were observed at a relatively early period and it was not possible to distinguish between the two annual brome grasses.

Other common annuals are Vulpia octoflora (Walt.) Rydb., Plantago purshii Roem. & Schult., Phacelia fremontii Torr., Eriophyllum wallacei Gray and Mimulus parryi Gray. In 1969 M. parryi was very common in both the Joshua tree-blackbrush and the blackbrush plots. An exceptionally wet year in 1969 probably accounted for the abundance of M. parryi but the density dropped off drastically in 1970 and this species was not seen in 1971.

The annuals Langloisia setosissima (Torr. & Gray) Greene, Eriastrum diffusum (Gray) Mason and Chorizanthe thurberi (Gray) Wats. were never recorded at the Joshua tree-blackbrush site, were rare at the juniper-blackbrush site but quite common at the blackbrush site.



Herbaceous plants were found in greatest abundance at the periphery of the blackbrush canopies. Only a few isolated plants were found beyond the canopy and the open areas between plants were essentially bare ground. This observation agrees with that of Beatley (1966).

Blackbrush cover, determined from the low altitude aerial photography, was 30 percent on the Joshua tree-blackbrush site, 29 percent on the juniper-blackbrush site and 20 percent on the blackbrush site. Density was not calculated because the multiple stem characteristic makes it impossible to distinguish a single plant from a group of plants.

Juniper cover was 5.4 percent on the juniper-blackbrush site and Joshua trees provided 2.1 percent cover on the Joshua tree-blackbrush plot. Desert almond (Prunus fasciculata Torr.), banana yucca (Yucca baccata Torr.), and Mormon tea (Ephedra spp.) are found at all three study sites but they provide less than 1 percent cover.

#### Leaf and Stem Anatomy

Adaptations of desert plants are usually reflected in their morphological or anatomical characteristics. Some of these adaptations were revealed in blackbrush leaf and stem anatomy.

A transverse section of a year old blackbrush stem shows a heavily sclerified pith with thick walls and simple pits. The secondary xylem is ring porous with no associated vertical parenchyma. The xylem cells are mainly lignified, thick-walled fiber tracheids with modified bordered pits and small lumens. Large multiseriate and small uniseriate rays are found in the xylem. Longitudinal views of the xylem reveals bordered pits in the side walls of the large vessels and a simple perforation in the end wall. The smaller vessels have either bordered pits or dense scalariform wall thickening. Simple pits are found in the parenchyma of the wood rays.

Brachysclereids are associated with the phloem fibers. The bast fibers of the phloem have simple, thick lignified walls, and small lumens. The sieve tube elements have oblique end walls and compound sieve plates. Exterior to the secondary phloem is a cap of bundle fibers (bast fibers), and cortical parenchyma is located exterior to the phloem fibers. The original phellogen originates in the cortical parenchyma and as growth proceeds, the new phellogen arises deep within the secondary phloem which pushes the bundle cap of fibers and old secondary phloem outwards.

Blackbrush appears to undergo "stem-splitting", a phenomenon in which the main stem splits into several smaller portions. Ginzburg (1963) reports that this stem-splitting phenomenon is very common in desert plants. He reported that aggregated rays in secondary xylem undergo suberization and split the axis into several units. Cross sections of mature stems of blackbrush indicate that perhaps the multiseriate rays undergo suberization and the stems split into separate units (Figure 21). Wallace and Romney (1972) report that blackbrush consists of a cluster of multi-stem segments which, when pulled apart, are attached to separate segments of the root system. This segmentation becomes more pronounced in mature shrubs.

The abaxial leaf surface contains four internerve depressions parallel to the long axis of the leaf. These grooves are evident early in leaf development but become more prominent as the leaf matures. The mesophyll is composed of palisade parenchyma near both abaxial and adaxial surfaces. The leaf is made rigid and supported by sub-epidermal collenchyma which is especially abundant near the adaxial surface (Figure 22). Sunken stomata are confined to the internerve depressions and have subsidiary cells protruding beyond the guard cells (Figure 23).

The leaf, as well as the stem epidermis, is covered by malpighian

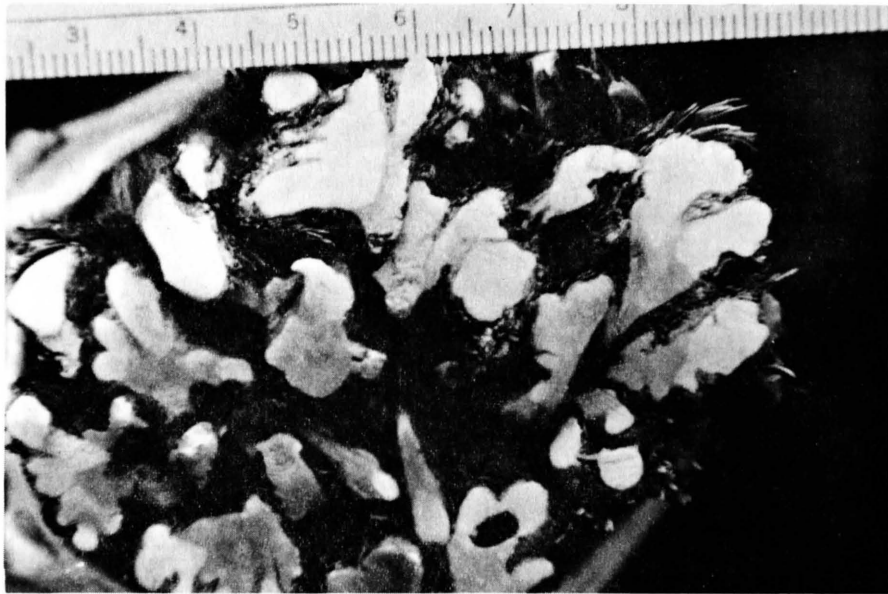


Figure 21 Cross section of mature blackbrush showing multiple stems.

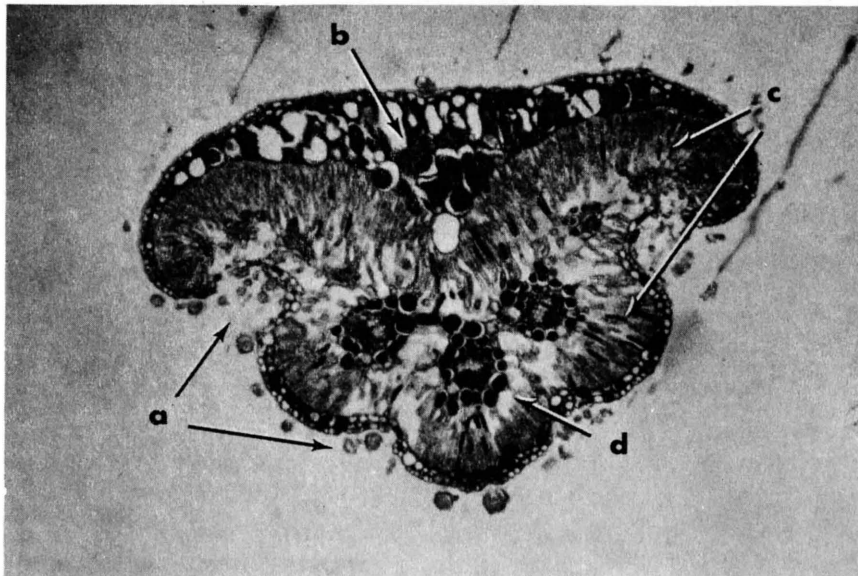


Figure 22 Cross section of young leaf showing four internerve depressions on abaxial surface (a), collenchyma cells (b), mesophyll tissue (c), and veins (d).

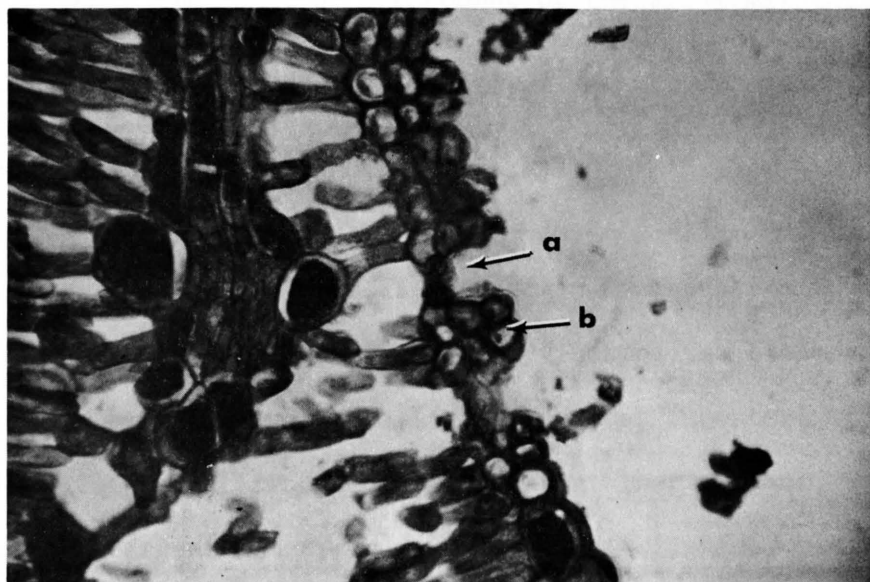


Figure 23 Sunken stomate (a) and protruding subsidiary cells (b) located in the internode depressions.

hairs which are oriented with their axis parallel to the long axis of the leaf. These trichomes are covered with small wart-like bumps which are very hard (Figure 24). The hardening appears to be a result of the addition of successive wall layers which eventually replace the living protoplast. The cuticle is thick in proportion to the size of the leaf, and is especially thick near the point of attachment of the epidermal hairs (Figure 25).

### Nutrient Content Analysis

A knowledge of the nutritive value of range plants is fundamental to the management of ranges for effective livestock production (Cook and Harris, 1968). This information is completely lacking for blackbrush ranges and at the present time livestock grazing is the most important use of this resource. The data presented here are values for ether extract, carotene, phosphorus, acid detergent fiber, crude protein, and lignin.

#### Ether extract

Ether extract is the fraction consisting of the fats and oils extracted by ether and consists of glycerides of fatty acids, free fatty acids, cholesterol, lecithin, chlorophyll, alkali substances, volatile oils and resins. The latter four, however, are not classed as nutrients (Crampton and Harris, 1969). Ether extract content for all three sites and for the entire collection period averaged 8.1 percent for the leaves and 4.8 percent for the stems (Table 9). There was an increase in ether extract from May through February. Analysis of variance indicated that these differences were significant at the 1 percent level of probability. The ether extract content of the leaves was higher than the stems and these differences were also significant at the 1 percent level of probability. No significant interactions between location and plant part or date and

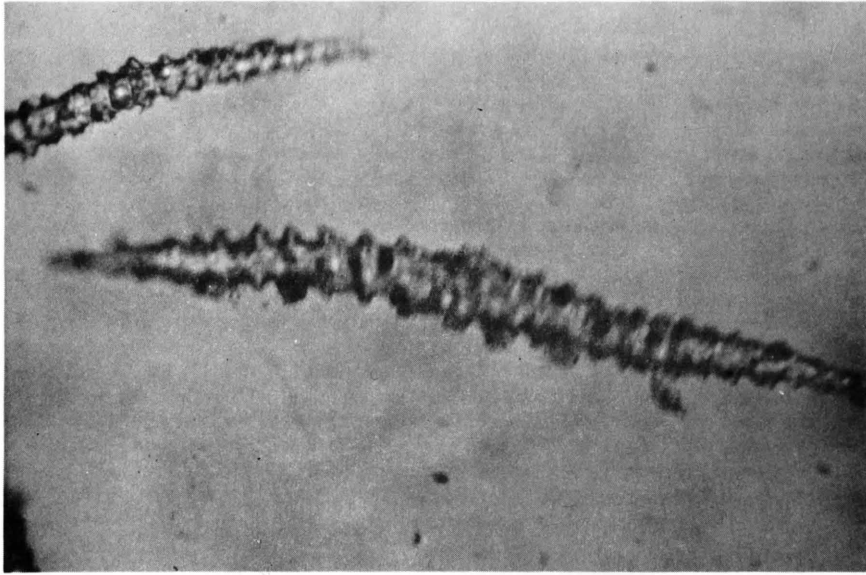


Figure 24 Malpighian hairs covered with small, hard, wart-like bumps.

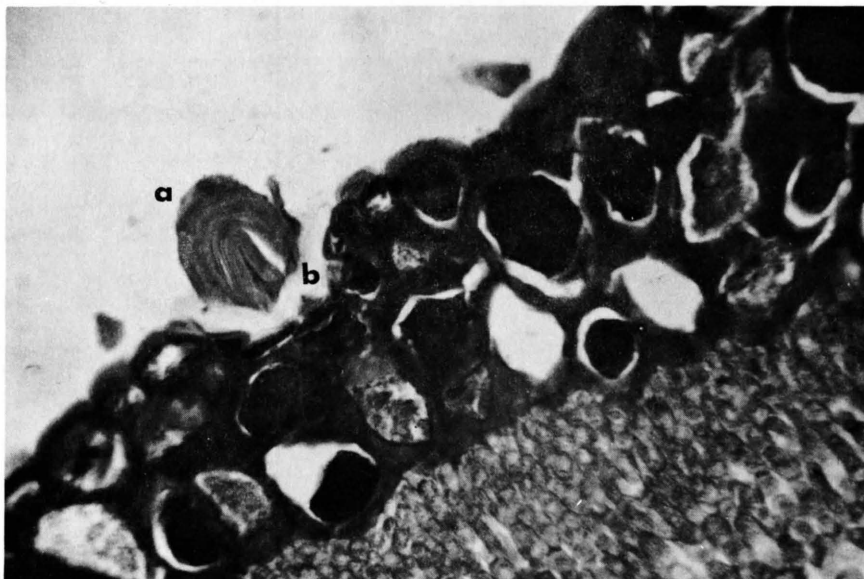


Figure 25 Malpighian hair oriented parallel to the internerve depressions showing successive wall layers (a) and thick cuticle (b) near the point of attachment.

Table 9 Nutrient content analysis of blackbrush leaves and stems. Combined data from 3 sites.

Collection Date	ether extract (percent)		carotene ( $\mu\text{g/g}$ )		phosphorus (percent)		acid detergent fiber (percent)		crude protein (percent)		lignin (percent)	
	leaves	stems	leaves	stems	leaves	stems	leaves	stems	leaves	stems	leaves	stems
May	6.6	3.7	68	20	0.14	0.13	23.3	45.3	8.8	3.8	8.1	14.8
August	7.4	4.0	71	30	0.10	0.11	25.3	52.5	7.2	4.6	8.9	18.4
November	8.8	5.1	93	34	0.11	0.10	23.9	52.2	7.4	2.2	8.7	19.6
February	9.5	6.6	110	35	0.11	0.10	23.4	51.5	7.3	4.1	8.3	18.0
Mean	8.1	4.8	86	30	0.12	0.11	24.0	50.4	7.7	3.7	8.5	17.7



plant part were revealed.

Ether extract content of blackbrush during the fall and winter seasons is comparable to that of big sagebrush and black sagebrush during the winter as reported by Cook and Harris (1968), and much higher than many other northern desert shrubs.

#### Carotene

Carotene, the precursor of vitamin A, averaged 86 ug/g for leaves and 30 ug/g for stems for all sites and collection periods (Table 9). Differences between dates of collection and between leaves and stems were significant at the 1 percent level of probability. Leaves were consistently higher than stems with the higher values occurring during the winter collection period. No other significant differences were found. Blackbrush leaves and stems exceed the minimum carotene requirements for both gestating and lactating animals throughout the year as recommended by Cook and Harris (1968).

#### Phosphorus

Phosphorus content averaged 0.12 percent for leaves and 0.11 percent for stems from all sites and collection periods (Table 9). Differences between the leaves and stems were significant at the 5 percent level of probability. Phosphorus content was highest during the spring collection period for both stems and leaves. Phosphorus differences among collection periods were significant at the 1 percent level of probability. Interactions among location and plant part, and date of collection and plant part were also significant at the 1 percent level of probability.

Blackbrush would be deficient in phosphorus for cattle and sheep according to the requirements set by Cook and Harris (1968) for both gestation (0.17 percent) and lactation (0.22 percent). Wallace and Romney



(1972) found the phosphorus content of blackbrush leaves to range from 0.06 to 0.20 percent for stems and 0.07 to 0.28 percent for leaves depending on soils and location.

#### Acid detergent fiber

Acid detergent fiber represents the lignicellulose complex of the plant and has been suggested as a replacement for crude fiber in the present Weende system. Acid detergent fiber contains essentially all plant cellulose and lignin. Cellulose can be determined by subtracting the amount of lignin from the acid detergent fiber (Colburn and Evans 1967).

Acid detergent fiber is much higher in the stems than in the leaves. Stem content is low in the spring and increases to a relatively constant level during the other collection periods (Table 9). Differences among dates of collection and between plant parts were significant at the 1 percent level of probability. Interactions between location and plant parts were significant at the 5 percent level and significant at the 1 percent level between date of collection and plant part.

#### Crude protein

Crude protein was 7.7 percent for the leaves and 3.7 percent for the stems from all sites and the entire collection period. The highest crude protein content was found in the leaves during the spring, but in the stems during the summer (Table 9). Differences between the leaves and stems were significant at the 1 percent level of probability. No significant differences among dates of collection or interactions were found.

Blackbrush stems are below the level of digestible protein as recommended by Cook and Harris (1968). Wallace and Romney (1972) reported that blackbrush leaves contain about 2 percent total nitrogen which would indicate a higher crude protein content than was found in this study.

### Lignin

Lignin is the indigestible portion of the plant and as expected, was much higher in the stems than in the leaves. The overall average was 17.7 percent for the stems and 8.5 percent for the leaves (Table 9). Lignin content was lowest in the spring for both leaves and stems.

Differences between dates of collection and between plant parts were significant at the 1 percent level of probability. The interaction between date of collection and plant parts was also significant at the 1 percent level.

Wallace and Romney (1972) reported a rather extensive mineral composition of blackbrush in their paper. This table is too lengthy to be reproduced here, but two important conclusions were that blackbrush leaves are low in sodium and moderately high in calcium.

### Simulated Brush Beating

Conversion of blackbrush to other vegetation types has been a desired goal of ranchers and land management agencies. Fire has been employed in this endeavor, but the results have been, at best, unpredictable. A desirable objective is to remove the old spinescent growth and stimulate new more succulent shoots. Brush beating appears to be a means of accomplishing this objective. A nonquantitative, purely subjective evaluation of simulated brush beating was conducted one growing season following the treatment. The success or failure of these treatments was determined by an evaluation of the treated plants according to the following rating scale and criteria. Excellent - good luxuriant growth of sprouts and well distributed about the stump; Good - good growth and fairly well distributed; Fair - generally short growth of sprouts or one or two good sprouts; Poor - poor response with few sprouts or very short growth; and Very Poor - plant

dead or very short growth. Figures 26, 27, and 28 illustrate representative plants that were treated.

Table 10 shows the response to brush beating treatment at each study site and all sites combined. These data indicate that fairly good results can be expected in areas similar to the blackbrush site but poor results from the areas similar to the Joshua tree-blackbrush site, and the juniper-blackbrush site.

Table 10 Results of simulated brush beating one year after treatment. Thirty plants were treated at each location.

Location	Excellent	Good	Fair	Poor	Very Poor
Joshua tree-blackbrush	0	2	12	7	9
blackbrush	10	8	10	1	1
juniper-blackbrush	2	7	9	10	2
total	12	17	31	18	12

One apparent mistake of this simulated brushbeating procedure was that many of the plants were cut off too near the ground resulting in their death. Chaining, cabling or brush beating would probably alleviate this situation and techniques should be developed to improve livestock forage production on predominantly blackbrush ranges.



Figure 26 Simulated brush beating showing excellent response.



Figure 27 Simulated brush beating showing good response.



Figure 28 Simulated brush beating showing poor response.

## DISCUSSION

Blackbrush, a desert shrub endemic to the Colorado River drainage and a monotypic species of the genus Coleogyne, occupies an intermediate position between the Larrea and Artemisia-Atriplex types as viewed by Beatley (1969), between Larrea and Artemisia (Randall, 1972) or between the hot and cold deserts as seen by Wallace and Romney (1972). Shantz in Tidestrom (1925) refers to a hopsage-blackbrush association which is a broad imbricating belt located between the northern and southern desert areas. Blackbrush, in the area of this study, occupies a belt between the creosote bush and the juniper-sagebrush zones. This vegetation zonation appears to be determined by differences in precipitation, soils, and temperature. The intermediate position of blackbrush results from higher precipitation than the Larrea zone but lower than the pinyon-juniper zone. Wells and Jorgensen (1964) determined the mean annual precipitation of several sites in each zone in southern Nevada with the following results: (1) pinyon-juniper 333 mm; (2) Coleogyne 206 mm; and (3) Larrea 124 mm. Differences in soils could also account for this zonation. Humphrey (1955) feels that the extremely abrupt boundaries of blackbrush apparently indicates a specific soil or soil moisture requirement. Differences in temperature could also account for this zonation. Wells and Jorgensen (1964) found that the Larrea zone is warmest, Coleogyne intermediate and pinyon-juniper coolest. Shantz in Tidestrom (1925) referred to this temperature factor when he said that the Joshua tree-blackbrush association is "characteristic of light pervious soil, and areas so covered would probably be dominated by creosote bush, were it not for unfavorable temperature conditions." Merriam (1893) observed that the desert plants of southwestern Utah are distributed in well marked belts or zones which he attributed to the temperature during

the period of growth and reproduction. The altitudinal zonation of blackbrush and other plant communities may also be a result of nocturnal ground inversions which produce layers of cold air near the ground, especially on calm clear nights. Turnage and Hinckley (1938) refer to this "cold air drainage" as a common phenomenon in the Sonoran Desert. The actual cause of this distinct vegetation zonation is undoubtedly a combination of all of these factors.

Blackbrush is not typical of other shrub genera in the Rosaceae family. Characteristics such as opposite leaves, lack of petals and four merous sepals are not commonly expressed in this family. The phylogenetic origin of blackbrush is also highly controversial and Stebbins (1972) lists blackbrush and several other genera of the Rosaceae family as monotypic or ditypic genera which have few or no close relatives. Stebbins and Major (1965) classify Coleogyne as a paleoendemic which is a relictual endemic left by extinction of its close relatives. They further define paleoendemics as ancient, exhibiting little variability, are often ecological specialists, and perhaps on the way to extinction. They do not now necessarily occupy the area where they arose. Their present area is relict, and they may be high polyploids.

The relictual endemics listed by Stebbins and Major (1965), which includes Coleogyne, are thought to be survivors of "once more widespread groups" whose adaptations to desert conditions are very old. They are considered relict in the sense that they were probably once more widespread than they are today, and their present distribution represents a restriction in their ranges with time.

Stebbins (1972) proposes the following reasonable hypothesis for



the taxonomic isolation of Coleogyne and other monotypic and ditypic genera. "Their taxonomic isolation makes them products of extensive evolution of semixerix shrubs during the upper Cretaceous period when arid areas were relatively numerous and widespread. With the onset of widespread mesic, equable climates at the beginning of the Tertiary, particularly the Eocene, only the hardiest of these xeric and semixerix forms could survive in specialized ecological islands that provided favorable habitats. When, during the Oligocene and Miocene periods, more xeric islands appeared and increased in size, those species that had survived the mesic interlude in special situations were now able to spread and in some instances to become very common. Nevertheless, their gene pools had become so much restricted during the long period when they existed only as small populations in refugial areas that they could not become diversified into a series of newly evolved species."

This is in contrast to Axelrod's (1950) thinking that these endemics have evolved from more humid vegetation of the Neotropical-Tertiary geoflora that became adapted to the expanding dry climate of the late Tertiary and Quaternary. He also recognizes that blackbrush, and other associated species, are not confined to the Sonoran-Mohave area, but range northward into the Great Basin Desert as well. He feels that they may have extended into this region in the Miocene and early Pliocene when the Madro-Tertiary flora invaded the lowlands of that province.

Fossil plant remains from pack rat middens and ground sloth dung in southern Nevada provide evidence that vertical displacement of vegetation zones has taken place. Xerophilous juniper woodlands descended to an elevation of 1100 meters which is 600 meters below the present lower limit of woodland at 36.5° north latitude in Nevada (Wells and Jor-



gensen, 1964). Desert and semidesert shrubs coexisted with the woodland trees throughout much of the span of elevation corresponding to the pluvial lowering of the woodland zone (Wells and Berger, 1967). The entire existing Coleogyne zone and at least the upper part of the existing Larrea zone around Frenchman Flat in southern Nevada were occupied by evergreen juniper woodlands during part of Pleistocene time (Wells and Jorgensen, 1964). Other evidence of this vertical vegetation displacement is the abundance of Joshua tree leaf fragments which have been recovered in ground sloth dung at an elevation of 610 meters indicating a decidedly different vegetation 8500 to 11,700 years ago than exists in that area today. Mehringer (1965) reviewed the literature from several sources and concluded that many areas of the arid western United States were not arid during parts of the late Pleistocene. During pluvial periods which were broadly contemporaneous with glacial maxima, rainfall was greater, temperatures lower, high mountains were perennially capped with snow, lakes dotted the landscape, through flowing drainage connected many presently isolated basins, vegetation zones were depressed by at least 1000 m, and many areas of the modern deserts and desert grasslands were covered by woodlands or parklands.

Blackbrush remains have been recovered from three late-Wisconsin Neotoma deposits in the Frenchman Flat area of southern Nevada. At that time blackbrush is thought to have extended 600 meters below its present lower limit of about 1300 meters which would have placed Tule Spring (703 m) within the zone of dominance by Coleogyne during pluvial times (Wells and Berger, 1967). However, blackbrush achenes recovered from Neotoma deposits were found at elevations of 1550, 1525, and 1280 meters which were age dated at  $9450 \pm 90$ ,  $9320 \pm 300$ , and  $7800 \pm 150$  years re-

spectively. These elevations are within the present zone of blackbrush dominance of 1220 to 1524 meters as reported by Beatley (1969). Tule Springs, however, is well below the present altitudinal range of blackbrush at that latitude.

Evidence is also available, from several lines of research, that indicates a worldwide climatic shift toward lowered annual precipitation and more extreme fluctuations of temperature and rainfall beginning in the Tertiary and continuing through the quaternary to the present (Johnson, 1968). Fitts (1965) provides tree-ring evidence of climatic changes in western North America. His data covers a period from the first half of the sixteenth century to the first 40 years of the twentieth century. The evidence shows alternating wet and dry extremes during this period. The twentieth century began with abundant precipitation but changed to widespread drought in the 1930's.

The preceding discussion provides evidence that changes have occurred in the climate with corresponding changes in the altitudinal zonation of the vegetation. Evidence also indicates that blackbrush is a relictual species which has existed in arid environments for a very long time and had its origin in the arid southwest.

Blackbrush is presently found on slopes of old alluvial ridges at approximately 1200 m in southwestern Utah. These soils are well drained, moderately permeable and derived from a variety of parent materials. An A-C horizon sequence is present and a petrocalcic horizon is located at 38 to 46 cm. Textures are mainly sandy loams with a high percentage of gravel.

Blackbrush is not found on the sands in this area but is replaced by sandsage. In southeastern Utah blackbrush is found on sands and is as-

sociated with more perennial grasses than is found in the region of this study. Perennial grasses are also more abundant in the blackbrush communities of southern Nevada especially on the south-facing slopes where shrub cover is sparse.

Large areas of southwestern Utah are covered with basalt flows which belong to the Grand Wash or Middleton Basalts. These flows are classified as Stage II by Hamblin and Best (1970) and suggested ages are two to three million years which would place their appearance in the Recent epoch of the Quaternary. The soils of the Beaverdam Mountain slopes are also of recent origin, belonging to the Basin and Range Physiographic Province characterized by Quaternary and Tertiary alluvial deposits (Gardner, 1941).

Blackbrush dominates the soils of the Beaverdam Mountain slopes but is missing from the basalt caps. Figure 29 shows big sagebrush on a basalt cap east of Santa Clara River and blackbrush on the alluvial soils at the same elevation west of the river. Blackbrush shows no sign of invading these sites although it is dominant on the alluvial soils located below the caps.

It is possible that the soils derived from the basalt caps are sufficiently different from the alluvial soils that blackbrush cannot exist on those areas. Comparisons between the soils on the caps and the alluvial soils was not done in this study so this remains an area for future study. Another plausible explanation is that these caps were originally blackbrush but the flows destroyed the vegetation and blackbrush has not reoccupied the sites. This latter proposal is in line with the thinking of Stebbins and Major (1965) that relictual species are survivors of once-more-widespread groups whose adaptations to desert conditions

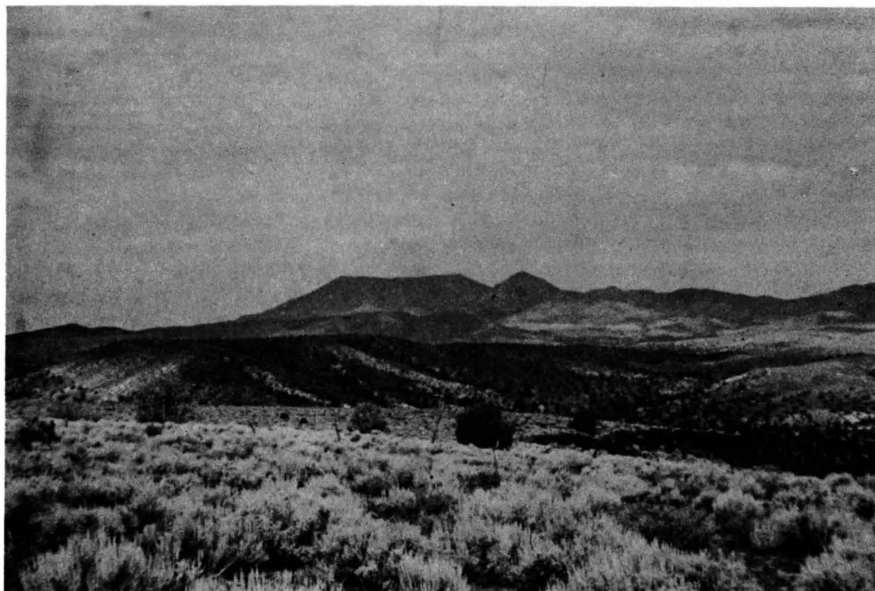


Figure 29 View looking west across Santa Clara Creek. In the foreground is a basalt cap covered with big sagebrush. Blackbrush is evident west of the creek where basalt is missing.

are very old and the present distribution represents a restriction of their range. Observations of burns and other areas where blackbrush has been destroyed indicates that blackbrush is extremely slow to reoccupy sites that it once dominated. Blackbrush fruits are rather large and heavy and have no visible means of rapid dispersal (Figure 30). This probably results in its slow movement into disturbed areas. The only visible means of dispersal is from rodent activity, or fruits being carried by storm runoff.

An interesting relationship exists between the distribution of blackbrush plants and soil nitrogen and phosphorus. The percent total nitrogen and available phosphorus are higher beneath the plants than the areas between plants. There is also a tendency for both nutrients to decrease with increasing depth of soil (see Tables 3 and 4).

Observations by Wallace and Romney (1972) may help explain the higher nitrogen content. They report that blackbrush is one of the desert species for which the acetylene reduction tests indicate nitrogen fixation in the roots. It was presumed that the nitrogen fixation system is symbiotic since this kind of process has been identified in three other members of the Rosaceae family and the endophyte involved there proved to be actinomycetes. Their feeling is that actinomycetal symbiosis may also occur with blackbrush, but this is purely subjective since no attempts were made to identify the system present.

Garcia-Moya and McKell (1970) also report a decrease in nitrogen content as the depth of sampling increased from the surface to 45 cm, and with lateral distance away from the center of desert shrubs. They conclude that "the importance of shrubs lies more in the way they serve as a reservoir for soil fertility in desert regions rather than in any signifi-



Figure 30      Closeup of blackbrush achenes. Some achenes are still enclosed in the sepals. Radicle emerges from the bent portion.

cant participation in symbiotic nitrogen fixation." They further state that shrubs contribute to desert fertility (1) by protecting the soil against wind erosion through retarding the movement of soil and increasing the accumulation of fine soil particles around their bases; (2) by protecting understory vegetation, such as annual grasses and forbs, from the effects of high temperature, thereby helping retain surface nitrogen and adding organic matter to the soil; and (3) by serving as a nitrogen reservoir through the storage of nitrogen in roots, leaves, and stems. Decomposition allows for the slow release of nitrogen and other elements to the ecosystem for use by other members of the plant community. The shrubs, therefore, create "islands of fertility." Deposition of blackbrush leaves at the onset of summer dormancy and the breakdown of numerous annuals adds a considerable amount of organic matter to the soil beneath the shrub canopy.

Growth of blackbrush is usually restricted to a period between late March and mid-June (see Figures 15, 16, and 17). Soil moisture usually reaches a peak during March and is slowly depleted as growth proceeds, unless a recharge occurs as a result of infrequent spring storms (see Figures 9 and 10). Air and soil temperatures appear to determine, to a large extent, the rate of stem elongation in blackbrush. Periods of warm weather results in abundant growth while cool periods retard the growth rate. Seed is produced only during years of adequate soil moisture. This moisture must come during the winter or during the period of spring growth. Seed does not ripen until late June or July and soon drops to the ground near the periphery of the shrubs.

Blackbrush goes into a summer dormancy in mid-June. At this time growth ceases and soil moisture is very low. This summer dormancy can be

broken if summer precipitation is adequate to reach the effective rooting zone. Summer storms are usually sufficient to wet the soil beneath the plant canopies but are rarely sufficient to penetrate more than a few centimeters in the region of maximum root biomass between the plants. Air and soil temperatures are very high at this time and soil moisture is usually present for only a short duration. Only in 1971 was summer precipitation adequate to break the dormancy of blackbrush. Wallace and Romney (1972) report a resumption of growth in the apparently dormant blackbrush following July and August rains in 1967 and 1968. They concluded, therefore, that the summer dormancy is a result of low soil moisture rather than high temperature, and that no chilling treatment is required to break summer dormancy. This summer dormancy has evolved to take advantage of water when it is present and blackbrush becomes dormant when water is lacking.

Seedlings of blackbrush are very rare in established stands and perturbations such as fire result in drastic changes in the plant composition. Seeds germinate sometime in February or March and often appear in clusters from rodent caches (Figure 31) although some seedlings do arise singly. Blackbrush seeds require stratification for a period of approximately 8 days at 4 C before germination occurs. Light is not required, during the stratification period, for germination and this is significant because light probably does not penetrate to the depth that rodents bury the seeds.

The stratification requirement has probably evolved as a mechanism to insure survival of blackbrush seedlings. If it were not for this requirement seeds produced in the spring would germinate during the summer storm period. Soil moisture would probably be adequate for germination but the soil dries out rapidly because of high soil and air temperatures





Figure 31 Cluster of blackbrush seeds germinated from a rodent cache. True leaves are evident.

and seedlings would die from desiccation. Germination in the spring, however, provides conditions which are more conducive to seedling survival and establishment.

Even though seeds germinate during the most favorable time of year seedling survival is very poor. Lack of soil moisture is apparently the predominant cause of seedling death and only a small number of seedlings survive the spring growing period. Rabbit and rodent activity also results in a considerable loss of seedlings. This is the most important factor in the loss of older, established seedlings. Clusters of young seedlings are also destroyed by rodents that eat off the cotyledons or dig the seedlings out of the ground. Seedlings of desert almond elongate more rapidly and appear to have a greater ability to survive than do the blackbrush seedlings. This may help explain the rapid invasion of desert almond onto areas where blackbrush has been destroyed by fire.

A wide variety of annuals and other herbaceous plants are found in association with blackbrush which is a contrast to the almost monospecific composition of the shrubs. The herbaceous plants are restricted to the periphery of the shrubs and few are found in the interspaces between plants. Soil moisture conditions are more favorable under the shrub canopy and soil nutrients are more abundant here than in the interspaces. The abundance of herbaceous species found under the canopy of blackbrush plants as well as germination of blackbrush seeds tends to dispel the possibility of blackbrush exerting an allelopathic effect on other plants or upon its own seedlings.

Blackbrush canopy-coverage ranges from 30 percent at the Joshua tree-blackbrush site to 20 percent at the blackbrush site. Rickard and Beatley (1965) report canopy-coverage values of 21.1 to 25.3 percent on five

Coleogyne plots, however, blackbrush contributed only 8 to 18 percent of the shrub cover. Their stands had more associated species than the nearly monospecific stands investigated in this study.

Density values for blackbrush are difficult or impossible to attain because of the multiple-stem feature of this plant. What appears to be a single plant is actually a group of plants in close association. One explanation of this phenomenon is that "stem splitting", which is common in desert shrubs, occurs in blackbrush. As reported for other desert shrubs by Ginzburg (1963), blackbrush appears to undergo separation along the multiseriate rays and splits into several units. This explanation is supported by observations of Wallace and Romney (1972). Another explanation is the survival of several seedlings that arise as a cluster and develop into many plants that resemble one. Stem splitting appears to be the most logical explanation because the number of growth rings may vary from 30 to 70 in one group. It is also noted that few if any seedlings survive from a seed cache. Older established seedlings always appear as a single plant and not as a cluster.

This multiple stem phenomenon is probably of survival value to the species. It is common to see a dead portion within the "plant." A typical single plant may die under unfavorable conditions but with the multiple stem arrangement one part can die but the other parts will survive and perpetuate the group. This stem splitting in blackbrush appears to be an adaptation to drought. Stebbins (1972) refers to the interxylary cork formation in big sagebrush and feels that this condition is an adaptation to severe conditions either cold or drought.

Leaf anatomy studies of blackbrush reveal adaptations to this harsh desert environment. Leaves are small 5 to 15 mm long, 1 to 1.5 mm wide,

and evergreen. The mesophyll is composed of palisade parenchyma near both the adaxial and abaxial surfaces. Stomates are sunken and confined to four internerve depressions located on the abaxial surface. Another adaptive feature is the abundant leaf drop following the spring growth period. With the onset of summer dormancy the older, outermost leaves drop. These adaptations result in conservation of water which is the limiting factor in the growth and development of blackbrush.

The greatest use of blackbrush in Utah is for winter and spring livestock grazing. It is usually regarded as a rather poor forage plant because of its low palatability, but animals are forced to eat the plant because it often exists in nearly monospecific stands. Sheep make better use of blackbrush than cattle, but it has a tendency to pull the wool out with its spinescent branches. The greatest value of blackbrush as a forage species appears to be its use by desert bighorn sheep.

Nutrient content analysis shows that blackbrush is markedly deficient in phosphorus for both gestation and lactation. Ether extract, the portion of the plant containing fats and oils, is comparable to that of big sagebrush and black sagebrush during the winter, and higher than the average of 10 cold desert shrub species reported by Cook and Harris (1968). The ether extract portion contains energy supplying constituents but this fraction is often high in essential oils which are not used by the animal but are voided through the urine. It is not known how much of the ether extract fraction of blackbrush is composed of essential oils. Crude protein content of stems is decidedly lower, but leaves comparable to the average of 10 cold desert shrub species during the winter as reported by Cook and Harris. Blackbrush leaves have a higher content of phosphorus, ether extract, and crude protein than do the stems. Lignin, the indigesti-

ble fraction, is much higher in the stems than in the leaves and average lignin values are comparable to those reported by Cook and Harris. Acid detergent fiber, which replaces crude fiber as a method of analysis is also much higher in stems than leaves. Cellulose, an important energy supplying constituent can be calculated by subtracting lignin from the acid detergent fiber. These values are 15.5 percent for leaves and 32.7 percent for stems averaged over the entire collection period. Carotene is high in both leaves and stems and greatly exceeds the minimum recommended requirements, for all seasons, as established by Cook and Harris.

Local livestockmen prefer to graze blackbrush ranges during the spring growing period because blackbrush is more palatable at this time. Ether extract, carotene, acid detergent fiber and lignin reach the minimum values at this time. Phosphorus and crude protein are highest during the same period. This indicates, therefore, that from the standpoint of animal nutrition this spring period is also the best time to graze blackbrush.

Blackbrush takes on a compact growth form because the terminal bud dies after one or two growing seasons which allows the lateral branches to elongate. After the terminal bud dies it becomes spinescent and objectionable to animals. Plants growing near corrals or water holes, where animals congregate, become heavily hedged (Figure 32), and animals readily eat this new growth. It is also apparent that the lower branches, referred to in this study as basals, produce longer shoots than the upper canopy branches (Figure 33). This new growth is not woody or spinescent and is more palatable and probably more nutritious than the woody portions. If a method could be developed that would remove the old woody growth and stimulate the more succulent growth blackbrush ranges would produce more useable and nutritive forage. Simulated brush beating indicates that this

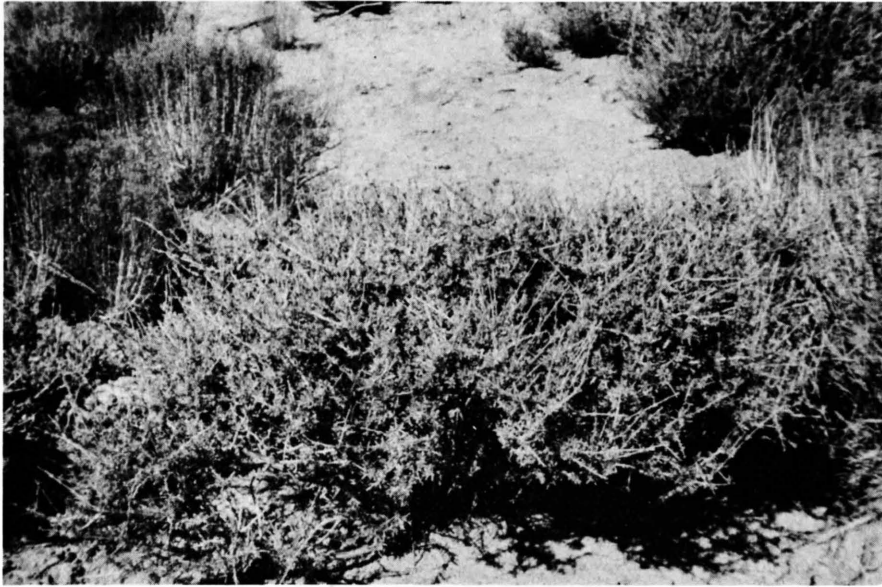


Figure 32 Hedged appearance of blackbrush as a result of heavy cattle grazing.



Figure 33 Long basal shoots originating from the lower portion of the stems.

can be accomplished through some means of chaining, cabling, or brush beating. This would provide more forage and yet would not destroy the existing vegetation and open up the plant community to other and perhaps less desirable species.

Bureau of Land Management personnel, as well as local ranchers, have long been interested in converting blackbrush ranges to other types of vegetation. Certain areas, such as near the mountains and in areas of deep soils have proven successful for conversion to introduced grasses (Figure 34). However, much of the blackbrush region does not appear suitable for this type of conversion because of shallow soils and poor soil moisture conditions.

Fire is a management tool that has been applied to many stands of blackbrush with varied results. Three burns, in close proximity to the study sites, have shown very different results. Figure 35 is a view of a burn located very close to the blackbrush study site and burned approximately 28 years ago. Observations of this burned site reveal a variety of vegetation that has taken over in lieu of blackbrush. The dominant browse species are turpentine bush (Thamnosma montana Torr. and Frem.), desert bitterbrush (Purshia glandulosa Curran), desert almond (Prunus fasciculata (Torr.) Gray), and in some areas big sagebrush (Artemisia tridentata Nutt.). It might well be argued that this burn is superior to the unburned range surrounding it, especially from the livestock forage standpoint.

A few miles to the south another old burn is evident (Figure 36). The date of this burn is not known but it should be obvious to the viewer that this site changed to a pure stand of snakeweed (Gutierrezia microcephala (D.C.) Gray), which I consider to be a much inferior forage plant





Figure 34 Successful seeding of introduced wheatgrasses on deep soils of this blackbrush region.

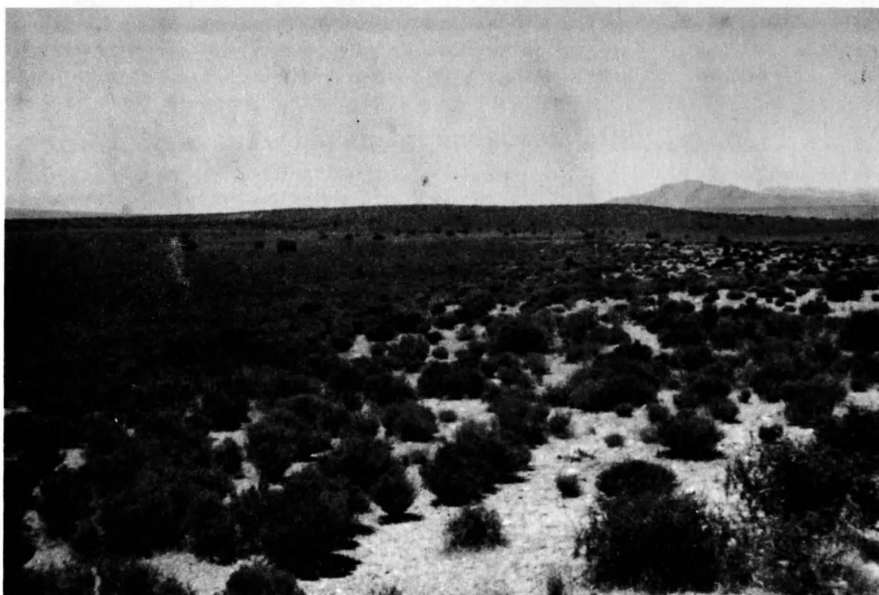


Figure 35 Edge of a burn located near the blackbrush study site. Fire occurred approximately 28 years ago.





Figure 36 Burned area taken over by snakeweed (Gutierrezia microcephala (D.C.) Gray)

compared to blackbrush. Figure 37 reveals another burn which occurred on an upland bench at some unknown date. Here the vegetation changed to an essentially pure stand of big sagebrush. The conclusions drawn from this discussion are that fire is a very effective tool for the destruction of blackbrush, but the after effects are, at best, very unpredictable. Personal observations show, however, that the B.L.M. has obtained favorable results from burning following chaining and reseeding.

The observations that blackbrush does not occur on basalt caps and does not return or is very slow to return to burned areas in southwestern Utah provides additional evidence that blackbrush is probably a relictual species and its present distribution represents a restriction of its range.

Further research is needed on this important but little studied species and the vegetation type it dominates. The following are suggested areas of investigation: (1) Synecological studies to determine and quantify differences in stands of blackbrush from different soils and climatic regions. This should include successional patterns, species composition, effects of grazing intensity, class of animals and season of use following burning or other perturbations; (2) methods of reestablishing blackbrush in areas where it has been destroyed. This is a desired goal of the U.S. National Park Service where blackbrush has been destroyed through mineral exploration and fire; (3) anatomical and morphological studies of blackbrush "plants" to determine whether the multiple-stem characteristic is due to stem splitting, which is common in desert shrubs, or whether it is due to a cluster of individual plants surviving from a rodent seed cache; (4) evaluate methods of removing old woody material from the plants and stimulating the production of basal shoots which are more palatable to



Figure 37 Burned area taken over by big sagebrush. Remnant stand of blackbrush and Utah juniper are evident in the background.

grazing animals. Chaining, cabling, and brush beating should be investigated as to their effectiveness and economical feasibility; and (5) test various species of grasses and shrubs as possible introductions for improving the quantity and quality of livestock forage.

## SUMMARY

Blackbrush is a rosaceous shrub endemic to the Colorado River Drainage. Large acreages where it dominates the vegetation are found in southern Utah, southern Nevada, southeastern California, northern Arizona, and southwestern Colorado, and yet it is probably the least studied major vegetation type in the United States.

Blackbrush has been described as occupying an intermediate position between the Larrea and Artemisia-Atriplex types, between the hot and cold deserts, or between the northern and southern desert areas. This intermediate position is probably a result of differences in precipitation, soils and temperature.

This species has been classified as a paleoendemic which is a relic-tual endemic left by the extinction of its close relatives. Blackbrush and other monotypic and ditypic genera are thought to be survivors of once-more-widespread groups and their present distribution represents a restriction in their ranges with time. Fossil evidence also indicates a vertical displacement of vegetation zones in southern Nevada and the area of this study during pluvial periods of the Pleistocene epoch.

The objectives of this study were to provide basic ecological information on this type which would serve as a basis for management decisions or which would lead to more basic or applied research. Parameters investigated in this study were climatic regimes, soil descriptions and analyses, soil moisture and temperatures, root profiles, phenology and growth, seed germination and seedling survival, understory herbaceous plants, leaf and stem anatomy, nutrient content analyses, and simulated brush beating.

The results of this study support the following conclusions:

1. The climate of the blackbrush region in southwestern Utah is characterized by cold winters and hot summers. Precipitation occurs mainly during the winter and summer with an annual average of approximately 300 mm. Summer temperatures exceed 40 C and winter temperatures of -24 C have been recorded.
2. Soils are sandy loams, exhibit an A-C horizon sequence, and are underlain with a petrocalcic horizon at approximately 40 cm. The soil pH ranges from 7.8 to 8.0. Total nitrogen and available phosphorus are higher beneath blackbrush plants than in the interspaces between the plants. Blackbrush is not found on sands or basalt caps in this region.
3. Soil moisture is most plentiful during the winter period just prior to the initiation of spring growth and is depleted during this growth period. Summer storms increase the soil moisture but it is usually not sufficient to cause a resumption of growth. Soil temperatures are highest during June and July. Summer soil temperatures of 46 C were recorded at 5 cm between plants and temperatures of 4 C were recorded during the winter at all probe locations.
4. Root biomass decreases with increasing depth and distance from the plants. The most effective rooting depth appears to be between 10 and 30 cm.
5. Summer dormancy of blackbrush is a result of soil moisture depletion rather than high temperature. Adequate summer precipitation will cause a resumption of growth which indicates that a chilling treatment is not necessary to break this dormancy.
6. Flowering and seed production is dependent upon winter precipitation. Soil moisture is usually adequate for growth but flowering occurs

only during the most favorable years. Growth occurs between the last week in March and mid-June. As long as soil moisture is adequate there appears to be a direct relationship between rate of growth and soil, and air temperatures.

7. Stratification at 4 C for eight days is necessary before blackbrush seeds will germinate. Light is not necessary for germination, which is advantageous because most seeds germinate from rodent caches placed rather deep in the soil. Seedling survival is very poor and few young blackbrush plants are evident. Young seedlings usually die as a result of inadequate soil moisture and older seedlings are destroyed by rodents and rabbits.

8. A considerable number of annual plants are associated with blackbrush, the most abundant being Bromus rubens L. Annuals are more abundant at the periphery of the shrubs than in the open areas between plants. This indicates a more favorable microenvironment near the shrubs and a lack of any allelopathic effect exerted by blackbrush.

9. Studies of blackbrush anatomy show features typical of many desert species. Leaf mesophyll is composed entirely of palisade parenchyma. Sunken stomates are confined to four internerve depressions located on the abaxial surface. Blackbrush stems appear to undergo "stem splitting", a phenomenon in which the main stem splits into several smaller portions.

10. Blackbrush has a low palatability rating and is deficient in phosphorus and protein during the winter grazing period. Livestock prefer the plant during the spring growing period and it is more nutritious at this time.

11. Burning has been employed as a means of converting blackbrush stands to more desirable forage species. This has been successful when

done in conjunction with reseeding, but the effects of fire are, at best, unpredictable. I do not recommend burning as a desirable management tool for this type.

12. Mature blackbrush plants develop a spinescent growth form and if this material can be removed the plant will probably be more attractive to livestock. Simulated brush beating removed this old growth and stimulated the production of more succulent basal shoots. Mechanical manipulation such as chaining, cabling, or brush beating are proposed as means of removing this old growth which will increase the available forage and leave the plant community relatively intact.

13. Research on blackbrush is suggested in the following areas: (1) synecological investigations to determine differences in stands of blackbrush found on different soils and in different climatic regions. Successional patterns as they relate to grazing intensity, class of animals, and season of use following burning needs immediate study; (2) methods of re-establishing blackbrush in national parks where it has been destroyed through mining exploration; (3) anatomical and morphological studies of blackbrush "plants" to determine whether the multiple-stem characteristic is due to stem splitting or survival of clusters of seedlings derived from a rodent cache; (4) evaluate methods of removing old woody material from the plants and stimulating the production of more palatable basal shoots; and (5) test various species of grasses and shrubs as possible introductions for improving the quantity and quality of livestock forage.



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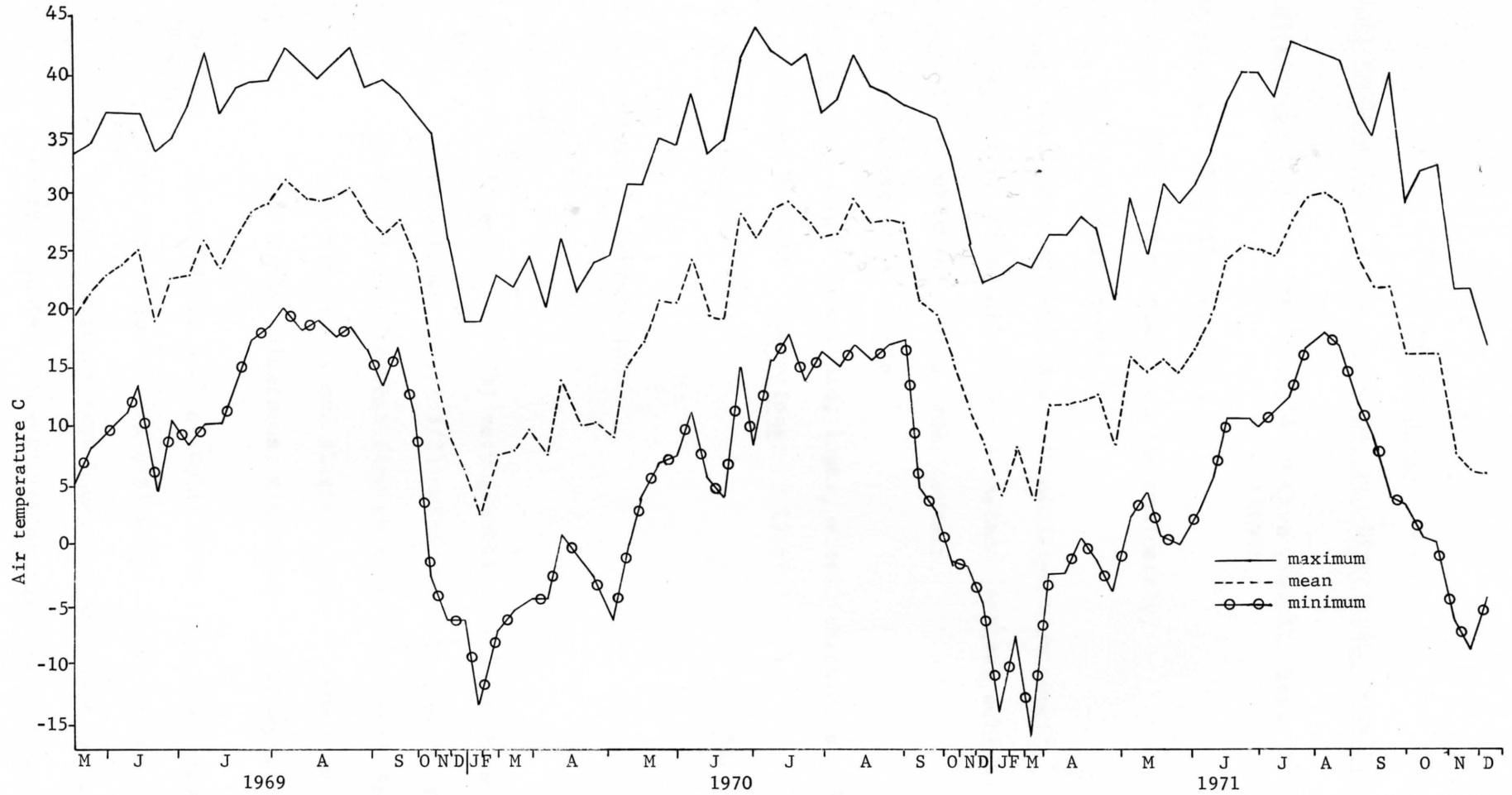
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Appendix I Seasonal air temperatures at the Joshua tree-blackbrush site.

## Appendix II

### Soil Profile Description of Joshua tree-Blackbrush Study Site

Washington Soil Survey Area No. 654 \* Cave gravelly loam, 2 to 7 percent slopes

Physiography: Old alluvial ridge.

Elevation: 1200 m above sea level (approximately)

Relief: 2% slope, east aspect.

Drainage: Well drained, moderate permeability, slow runoff.

Parent Materials: Mixed alluvium - limestone, gneiss, schist, sandstone.

Vegetation: Blackbrush, Joshua tree, annuals.

Erosion: Moderate water erosion.

Classification: Typic Paleorthid, loamy, mixed, thermic, shallow.

Sampling Date: 8/19/69    Operations: 8/19/69

Observers: Mortensen, Bowns

Date: 8/19/69

\*Name is subject to correlation

#### Soil Profile:

- |    |                 |   |
|----|-----------------|---|
| A1 | 0-3cm<br>(0-1") | Brown (7.5YR 5/3) very gravelly loam (50% fine gravel), dark brown (7.5YR 3/2) moist; weak thin platy structure that breaks to weak fine granular soft, very friable, slightly sticky and slightly plastic; few fine roots; moderately calcareous; clear smooth boundary. |
| C1 | 3-9cm<br>(1-3") | Brown (7.5YR 5/4) gravelly loam; (35% fine gravel), brown to dark brown (7.5YR 4/3) moist; weak, medium subangular blocky structure that breaks to weak fine granular soft, very friable, slightly sticky and slightly plastic; few                                       |

very fine and fine roots; many very fine and fine pores; moderately calcareous, clear smooth boundary.

- C2 9-21cm (3-8") Brown (7.5YR 5/4) loam (15-20% fine gravel) brown to dark brown (7.5YR 4/4) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and few medium roots; many very fine and fine, few medium pores; strongly calcareous, clear smooth boundary.
- C3 21-38cm (8-15") Brown (7.5YR 5/4) gravelly loam; (30% gravel and a few cobble); brown to dark brown (7.5YR 4/4) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and medium and few large roots; common very fine and fine and few medium pores; very strongly calcareous, abrupt wavy boundary.
- Ccam 38cm (15") Indurated hardpan.

NOTE: Immediately under blackbrush plants the A1 horizon ranges to a thickness of 8 cm. It is wind, and/or water deposited material. The hardpan in this profile occurs at a depth of 30 cm under the blackbrush plant in this profile.

Soil Profile Description of Blackbrush Study Site

Washington Soil Survey Area No. 654 \* Cave gravelly loam, 2 to 7 percent slopes

Physiography: Old alluvial ridge.

Elevation: 1200 m above sea level (approximately).

Relief: 2% slope, southeast aspect.

Drainage: Well drained, moderate permeability, slow runoff.

Parent Materials: Mixed alluvium-limestone, gneiss, schist, sandstone.

Vegetation: Blackbrush, scattered juniper, desert almond, cheatgrass.

Erosion: Moderate water erosion.

Classification: Typic Paleorthid, loamy, mixed, thermic, shallow.

Sampling Date: 8/19/69

Operations: 8/19/69

Observers: Mortensen, Bowns

Date: 8/19/69

\* Name is subject to correlation.

Soil Profile:

- |    |                  |  |
|----|------------------|--|
| A1 | 0-3cm<br>(0-1")  | Brown to dark brown (7.5YR 4/3) very gravelly loam (50% fine gravel), dark brown (7.5YR 3/2) moist; weak fine granular structure; soft, very friable, slightly sticky and nonplastic; common very fine and fine roots; moderately calcareous, clear smooth boundary. |
| C1 | 3-24cm<br>(1-9") | Brown (7.5YR 5/4) gravelly loam; dark brown to brown (7.5YR 4/3) moist; moderate medium subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; common fine and few medium roots;  |



many very fine and fine and few medium pores; strongly calcareous, clear wavy boundary.

C2 24-41cm Brown (7.5YR 5/4) gravelly loam, dark brown to brown (9-16") (7.5YR 4/4) moist; moderate medium subangular blocky structure; slightly hard, friable, sticky and slightly plastic; common fine and medium and few large roots; many fine, common medium and few large pores; very strongly calcareous, abrupt wavy boundary.

Ccam 41cm Indurated hardpan.  
(16")

NOTE: The A1 horizon ranges to 8cm immediately under the blackbrush plant. Also a thin 1/2cm thick O1 horizon of leaves and small twigs occurs at the base of the plants.

Soil Profile Description of Juniper-Blackbrush Study Site

Washington Soil Survey Area No. 654 \* Pastura loam, 0 to 10 percent slopes

Physiography: Old alluvial ridge

Elevation: 1200 m above sea level (approximately)

Relief: 2% slope, SE Aspect.

Drainage: Well drained, moderate permeability, slow runoff.

Parent Materials: Mixed alluvium from basalt limestone, gneiss, sandstone

Vegetation: Blackbrush, juniper, desert almond.

Erosion: Moderate.

Classification: Typic Paleorthid

Sampling Date: 8/19/69    Operations: 8/19/69

Observers: Mortensen, Bowns

Date: 8/19/69

\* Name subject to correlation

Soil Profile:

- |                         |   |
|-------------------------|---|
| A1    0-7cm<br>(0-3")   | Light brown (7.5YR 6/3) loam, dark brown to brown<br>(7.5YR 4/4) moist; moderate fine granular structure, with<br>the upper three centimeters being moderately thick platy;<br>soft, friable, slightly sticky and slightly plastic;<br>abundant fine and very fine vesicular pores; strongly<br>calcareous; abrupt smooth boundary. |
| C1    7-31cm<br>(3-12") | Brown (7.5YR 5/4) heavy loam; dark brown to brown<br>(7.5YR 4/4) moist; moderate medium subangular blocky<br>structure; slightly hard, friable, sticky and slightly   |

plastic; common very fine and fine roots; common very fine and fine and few medium pores; very strongly calcareous, clear wavy boundary.

C2ca 31-46cm (12-18") Light brown (7.5YR 6/4) gravelly loam, brown (7.5YR 5/4) moist; massive slightly hard, friable, slightly sticky and slightly plastic; common fine and medium and few large roots; many very fine and fine and few medium pores; very strongly calcareous, abrupt smooth boundary.

Ccam 46cm (18") Indurated hardpan.

Note: The A1 horizon ranges to 11cm at the base of blackbrush plants.

## VITA

James E. Bowns

Candidate for the Degree of

Doctor of Philosophy

Dissertation: An Autecological Study of Blackbrush (Coleogyne ramosissima Torr.) in Southwestern Utah.

Major Field: Ecology

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Education: Attended Castle Gate elementary school, Helper Junior High; graduated from Carbon High School in 1950; attended Carbon Junior College, University of Utah, obtained Bachelor of Science Degree in Forest-Range Management in 1961, Master of Science Degree in Range Management in 1963 at Utah State University; did graduate work in plant ecology at University of Saskatchewan.

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